925

Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Copyright, 1939, by Federation of Sewage Works Associations

Vol. XI November, 1939 No. 6

Sewage Research:

Studies on Activated Sludge. I. Bulking of Sludge by Means of Carbohydrates. By R. S. Ingols and H. Heukelekian 927

Activated Sludge Oxidations. IV. The Influence of Temperature Upon the Rate of Oxygen Utilization by Activated Sludges. By Clair N. Sawyer and Gerard A. Rohlich 946

Studies on the Methane-Producing Bacteria. IV. Growth of Methane-Producing Bacteria in Supernatant Sludge Liquors. By H. Heukelekian and Bernard Heinemann 965

Plant Operation:

Sewage Treatment at Gary. By L. R. Howson 994

Sludge Disposal at the Minneapolis-St. Paul Plant. By George J. Schroepfer 971

Filtration and Incineration at Buffalo. By C. R. Velzy 988

The Flash Drying System of Sludge Disposal. By Wm. Dundas 1006

Operating Problems in Starting the Southwest Sewage Treatment Works of The Sanitary District of Chicago.

Introduction—By A. H. Goodman 1020

Treatment Problems—By C. T. Mickle 1020

Chemical Control—By G. G. Poindexter 1025

Mechanical Organization—By Roy C. Hageman 1030

Industrial Wastes:

Treatment of Sulfur Dye Waste by the Activated Sludge Process. III. Dewatering of Activated Sludge Obtained by Treatment of a Sulfur Dye-Sewage Mixture. By Ralph Porges and Henry J. Miles 1038

Packinghouse Wastes and Sewage Treatment at Austin, Minnesota. By Paul Hansen and K. V. Hill 1045

Operators' Reports and Suggestions:

Fine Screening of Sewage. By Joseph A. Muldoon 1054

The Joint Meeting for Sewage Disposal of Certain Municipalities in Essex and Union Counties, N. J. 1067

Sludge Gas Engine Operation at Michigan City, Indiana. By H. H. Jones 1074

Small Plant Operators' Clinic 1076

Excerpts from "Minneapolis-St. Paul Sanitary District Report for 1938." By George J. Schroepfer 1078

Extracts from First Annual Report of the Buffalo Sewer Authority—1938–1939. By Charles R. Velzy 1083

Editorial:

Sludge Disposal at Minneapolis, Buffalo and Chicago 1089

Proceedings of Local Associations:

Central States Sewage Works Association 1091
New England Sewage Works Association 1093
New York State Sewage Works Association 1095

Reviews and Abstracts

Report of the (British) Water Pollution Research Board for the Year Ended 30th June, 1938. (With Report of the Director of Water Pollution Research) 1097
Some Chemical and Bacteriological Properties of Trade Wastes Containing Chromates. By H. E. Monk 1099
Cheltenham's Remodelled Sewage Disposal Works. By G. Gould Marsland 1100
The Application of Fluorescent Indicators to the Acidimetry of Trade Effluents. By Denis Dickinson 1101
The System Activated Sludge Oxygenated Water. By Denis Dickinson 1102

Author Index iii

Subject Index vi

JOIN YOUR STATE OR LOCAL SEWAGE WORKS ASSOCIATION

AFFILIATE WITH THE NATIONAL FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Members of the Federation receive

THE SEWAGE WORKS JOURNAL

for $1.50 per year

Non-members' subscription fee $3.00 per year, which includes subscription at $2.00 and service information fee of $1.00; Canada, $3.50; other countries, $4.00.

Send Subscriptions to

WM. W. BUFFUM, Business Manager

654 Madison Ave.

New York, N. Y.

Sewage Research

STUDIES ON ACTIVATED SLUDGE BULKING*

I. BULKING OF SLUDGE BY MEANS OF CARBOHYDRATES

By R. S. Ingols and H. Heukelekian

Asst. and Assoc., Dept. Water and Sewage Research, New Brunswick, N. J.

There is ample evidence in the literature that the addition of carbohydrates to sewage causes a rapid and severe bulking of activated sludge. Smit (13) studied the bulking of sludge with several different carbohydrates and found that although the rates of bulking differed, all eventually caused the sludge to bulk. Instances of severe bulking have been reported in general as due to discharge of distillery and carbohydrate wastes. Bulking of activated sludge in plant operation occurs frequently, in fact most generally, in the absence of appreciable quantities of carbohydrates. Work on bulking in the absence of carbohydrates will be reported in a later paper. The results and discussion on bulking caused by carbohydrates in this paper will be concerned with certain general principles. The main questions are:

What property of the carbohydrates produces the bulking? Carbohydrates are readily available as food for energy, give any apparent low electrode potential, and must have a readily available source of nitrogen in order to build new protoplasm. What part does the condition of the sludge play in its bulking when caused by carbohydrates? The condition of activated sludge is best measured at present by (1) the stage of oxidation as indicated by the nitrate content and (2) the settling index. Other indices such as oxygen utilization rate, ash, etc. have been suggested. Neither the nitrate nor the settling index gives a true insight of the condition of the sludge and some of the inconsistencies in the evaluation of the different sludges must be traced to the lack of proper methods of determining the condition of the sludge. The authors consider it possible that the oxidation-reduction potential might give a clearer insight into actual condition of a sludge, but as yet have not been successful in coping with the difficulties involved in such a measurement either electrometrically or colorimetrically.

Methods

The study of bulking has been carried out in glass cylinders holding one liter of a mixture of activated sludge and sewage. In the early part of the study, the carbohydrates and other foods studied were

* Journal Series Paper N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

added to activated sludge with sewage. Sewage does not remain constant in strength and so its use was discarded in favor of mineral dilution water to which known amounts of foods could be added at regular intervals. The mineral water contained:

Salt	Parts per Million
Calcium chloride	47
Potassium hydrogen phosphate	40
Sodium bicarbonate	100
Ferric chloride	5
Magnesium sulfate	50

These minerals were added to New Brunswick tap water, which has a hardness of about 50 p.p.m. The minerals approximate the relative mineral analyses of the local sewage and contain the essential elements for bacterial metabolism. Activated sludge samples were obtained from various plants and diluted to the desired sludge concentration and the desired carbonaceous and nitrogenous substances added from concentrated stock solutions. The sludge was settled at each feeding, the supernatant liquor drawn, and fresh "mineral water" and the nutrients added. This prevented the accumulation of any excess food and of any toxic by-products of bacterial metabolism.

The approximate solids concentration of the sludges were determined by the centrifuge (12). For the accurate determination of the solids needed for the bulking study a large aliquot (200 ml.) was settled and the supernatant liquor discarded, if clear, and the sludge centrifuged. The supernatant liquor was decanted and the sludge washed with distilled water into a tared silica dish, dried and weighed. The sludge volume was determined after settling for 30 minutes in a liter cylinder.

The quantity and type of carbonaceous and nitrogenous materials fed at each change were varied with each experiment.

The method for determining sugar concentrations has been used previously (10). Ammonia was determined by Nesslerization: nitrates, by the method given in *Standard Methods for Water and Sewage,* the sludge index calculated by the method of Mohlman (8).

Results

A. Effect of Material Fed.—When organisms are fed an excess of food above their requirements for growth and reproduction, they frequently store a portion of the excess as fat. Fats are lighter than water and it was considered possible that they might be the cause of the decreased rate of settling of activated sludge. Several different foods, glucose, starch, peptone, and calcium butyrate were fed in equivalent amounts to sludge together with sewage. Their effect upon the sludge index and fat content of the sludge was noted (Table I). The sludges fed with sugar and starch became bulky, but their fat contents did not increase. The samples fed peptone and calcium butyrate showed a decrease in the sludge index as well as a low fat content. A

TABLE I.—*Effect of Type of Food Fed to Activated Sludge Upon its Settling Index and Fat Content*

Substance Fed	Quantity of Nutrients Fed in Addition to Sewage	Sludge Index		Fat on Dry Basis*	Sphaerotilus
		Initial	Final*		
	P.p.m.			%	
Sewage	—	120	132	7.25	+
" glucose	600	120	307	6.2	+++
" starch	540	120	243	5.7	+++
" peptone	500	120	97	4.8	+
" calcium butyrate	580	120	121	4.3	+++

* After 5 feedings.

high sludge index was not correlated with a high fat content. This was repeated with the same results.

Frequently at activated sludge plants a quantity of fine floc escapes over the weirs with the effluent. Some of this flocculent material was collected by pouring the effluent through cheesecloth and washing off the floc with distilled water. The floc was permitted to settle, then centrifuged and dried. The dried floc was analyzed for its fat. Some sludge from the bottom of the tank (return sludge) was also analyzed for its fat content. The return sludge had 6.7 per cent fat while the fine floc had 7.7 per cent fat.

The results in Table I show that glucose when added to sewage caused the sludge to bulk while an equivalent amount of peptone caused a decrease in the settling index of the sludge. The presence of large amounts of nitrogen in peptone and its absence in sugar led to the hypothesis that the nitrogen as well as the carbon played an important role in the bulking of activated sludge. It was necessary to know what forms of nitrogen, if any, might be used with the glucose to prevent bulking. In Table II are given results on the effect of different types

TABLE II.—*Effect of Various Nitrogenous Substances Added to Sewage Upon Bulking Due to Sugar*

Materials Added to Sewage			Suspended Solids		Sludge Index	
Glucose C	Nitrogen		Initial	Final*	Initial	Final*
	Compound	Quantity				
P.p.m.		P.p.m.	P.p.m.	P.p.m.		
0	—	—	1300	1300	138	135
240	—	—	"	2100	"	410
240	NH_4Cl	24	"	2100	"	266
240	Urea	24	"	2300	"	163
240	Peptone	24	"	2500	"	356
240	$NaNO_3$	24	"	2100	"	450
0	Peptone	24	"	1600	"	125

* After 5 doses.

of nitrogenous materials on the bulking caused by sugar. The urea plus the nitrogen in the sewage prevented bulking of the sludge or at least markedly retarded bulking. Sodium nitrate and peptone had only little effect. Ammonium chloride helped to retard, but was not so effective as urea. Its use was discontinued because the stable chloride ion aided the nitrate anion (produced as the result of nitrification) in lowering the pH to less than 5.0 in five hours aeration. These results have been published elsewhere (5).

For the remaining experiments, the "mineral water" previously described was used instead of sewage. In Table III the effect of feeding a constant amount of sugar with varying amounts of urea is shown. The quantities of ammonia and nitrate produced and the amount of sugar remaining in this experiment are shown in Table IV for the first and third doses. In the absence of nitrogen for metabolism glucose was not utilized, the quantity of solids and sludge index failed to increase. As the quantity of nitrogen increased the amount of sugar

TABLE III.—*Effect of Various Amounts of Nitrogen Upon the Bulking of Activated Sludge Due to Sugar*

Materials Fed		C–N Ratio	Suspended Solids		Sludge Index	
Glucose C	Urea N_2		Initial	Final*	Initial	Final*
P.p.m.	P.p.m.		P.p.m.	P.p.m.		
240	0.0		1350	1370	74	69.5
"	6	40	"	1690	"	190
"	12	20	"	1900	"	450
"	24	10	"	1920	"	230
"	36	6.6	"	1980	"	91
"	48	5.0	"	1960	"	182
"	60	4.0	"	1960	"	92

* After 5 doses.

TABLE IV.—*Effect of Feeding Sugar Upon the Rate of Sugar Utilization and Nitrification*

Materials Fed			Chemicals Present After 6 Hours Aeration					
			First Dose			Third Dose		
Glucose C	Urea N	C–N ratio	NH_3N	NO_3–N	Glucose C	NH_3–N	NO_3–N	Glucose C
P.p.m.	P.p.m.		P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
240	0		0	0	192	0	0	204
"	6	40	0	7.2	192	0	0	140
"	12	20	0	11.2	192	0	0	40
"	24	10	2.4	20	188	0	0	0.0
"	36	6.6	12	20	182	0	6.4	0
"	48	5	16	24	176	8.0	16.0	0
"	60	4	20	20	176	9.0	22.0	0

utilized increased. At a ratio of 10 C to 1 N (on the basis of glucose and urea added) there was no carbon as sugar or nitrogen as ammonia or nitrates left in solution. The C–N ratio of 10 was approximately correct to permit complete utilization of both the sugar and the ammonia without an excess of either. As the quantity of nitrogen increased, or the C–N ratio decreased below 10, there was an excess of nitrogen which appeared as nitrates and ammonia. The increases in the sludge indices were also affected by the quantity of nitrogen. The highest sludge index was obtained with the C–N ratio of 20; ratios lower and higher than 20 did not cause the sludge to bulk as much in the same number of feedings.

The experiment was repeated in essentially the same way for a longer period than the previous one. At each dose 600 p.p.m. of sugar was fed along with different quantities of urea nitrogen. The results are presented in Fig. 1. Bulking (increase in sludge index) did not

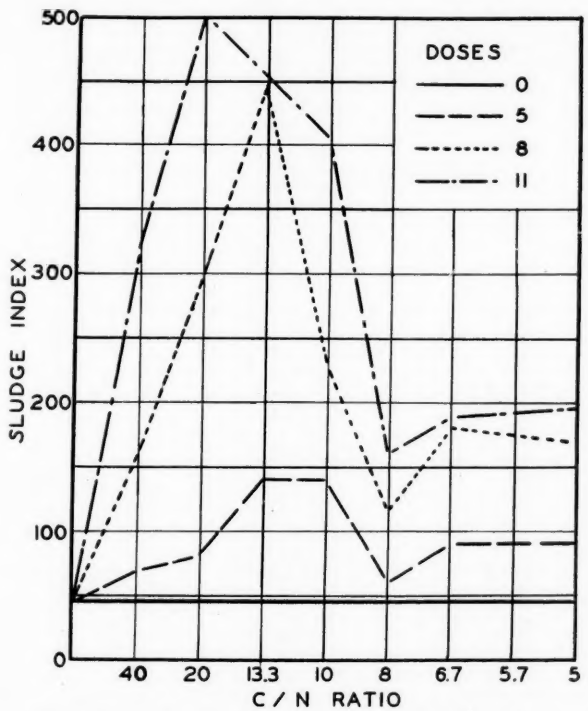


FIG. 1.—The effect of the carbon-nitrogen ratio of the materials fed (glucose and urea) upon changes in the sludge index.

occur when sugar was fed as much as eleven times in the absence of nitrogen. Bulking became progressively severe with a C–N ratio of 40 and 20 in the materials fed. The sludge index decreased below C–N ratios of 13.3. At a C–N ratio of 8 the sludge index was only about twice as high after the 11th dose as the initial value. With C–N ratios

narrower than 8 a slight further increase in the sludge index was obtained. Thus it appears that sugar bulking can be controlled to a certain extent by the addition of adequate amounts of an available source of nitrogen such as urea.

TABLE V.—*Effect of High Sugar Concentration Upon Bulking at a Constant Carbon-Nitrogen Ratio of 2.4*

Number of Additions	Chemicals Added		Glucose Used		Nitrates Present After 6 Hrs. N	Susp. Solids	Sludge Index
	Glucose C	Urea N	Time	Quantity C			
	P.p.m.	P.p.m.	Hrs.	P.p.m.	P.p.m.	P.p.m.	
0	240	100	6	80	11.0	1450	48
4†	240	100	3	240	20.0	1890	56
3	240	100	3.5	240	24.0	1950*	64
3	720	300	3.0	720	4.8	3050*	310

† After the fourth dose, sample was divided into two portions and each portion fed three more times at concentrations indicated above.

* Sludge concentration at beginning of fifth run for each fraction, 1450 p.p.m.

In order to determine the effect of increased sugar concentration on the rate of bulking of activated sludge a portion of sludge was dosed 4 times with 240 p.p.m. glucose carbon and 100 p.p.m. urea nitrogen (Table V). During this period the sludge index increased only slightly (from an initial 48 to 56). The sludge was then divided into two portions, one portion dosed as before (240 p.p.m. glucose carbon and 100 p.p.m. urea nitrogen) while the second portion received 720 p.p.m. glucose carbon and 300 p.p.m. urea nitrogen, maintaining the same C–N ratio but increasing the amount of each proportionately. After three doses with the smaller amounts of sugar the sludge index was 64, while that with larger doses of sugar, the index increased to 310. In other words, at a constant and adequate carbon-nitrogen ratio, the concentra-

TABLE VI.—*Effect of Sugar Concentration Upon Bulking*

Chemicals Fed		C–N Ratio	Doses	Suspended Solids		Sludge Index	
Sugar	Urea N			Initial	Final	Initial	Final
P.p.m.	P.p.m.		No.	P.p.m.	P.p.m.	—	—
200	40	5	6	540	1190	150	380
100	20	5	12	"	1240	"	306
50	10	5	13	"	960	"	193
25	5	5	13	"	685	"	131
12.5	2.5	5	13	"	592	"	118
200	16	12.5	6	"	1265	"	285
100	8	12.5	8	"	1120	"	320
50	4	12.5	11	"	800	"	550
25	2	12.5	13	"	640	"	155
12.5	1	12.5	13	"	530	"	150

tion of the sugar fed is an important factor. A carbon nitrogen ratio of 2.4 with a comparatively low sugar concentration (600 p.p.m. glucose) does not bulk readily but when the sugar dose is increased threefold, bulking readily takes place in spite of the fact that the same C–N ratio may be maintained.

It was natural to expect that if the sugar was added at low enough concentration there would be no bulking. Accordingly, an experiment was conducted with decreasing sugar concentration and with two different carbon-nitrogen ratios. The results are given in Table VI. With a carbon-nitrogen ratio of 5, 200 p.p.m. glucose carbon bulked after six doses, while 100 p.p.m. glucose carbon required twelve doses to produce a bulky sludge. With 50 p.p.m. glucose carbon the sludge index had increased from an initial 150 to 193 after thirteen doses. On the other hand, smaller doses of glucose gave indices lower than the initial value after thirteen doses. Thus, in the presence of ample supply of nitrogenous material, bulking is a function of the sugar concentration. Similar results in respect to bulking with different sugar concentration were obtained with a nitrogen supply just sufficient to permit the complete utilization of sugar but not in excess to allow nitrification

TABLE VII.—*Effect of Sludge Concentration*

Chemicals Fed		Feedings	Conc. of Susp. Solids		Increase in Solids	Sludge Index	
Glucose C	Urea N		Initial	Final		Initial	Final
P.p.m.	P.p.m.	No.	P.p.m.	P.p.m.	P.p.m.		
240	100	3	470	1090	620	82	198
240	100	3	1250	1735	485	82	132
240	100	3	3100	3440	340	82	93

(C/N ratio of 12.5). The most rapid bulking, although not the highest sludge index, was obtained with the highest sugar concentration, 200 p.p.m. carbon as glucose. With 100 and 50 p.p.m. glucose carbon it required a greater number of doses than with 200 p.p.m. to make the sludge bulk, but when this occurred it was more intense than with higher sugar concentration. With 25 and 12.5 p.p.m. glucose carbon, the sludge index did not increase after thirteen doses.

The effect of sludge concentration was studied by holding the sugar constant at 600 p.p.m. at each addition and varying the sludge concentration from 500 p.p.m. to 3100 p.p.m. At the end of three feedings (Table VII) the sludge index at the highest sludge concentration increased little, while a very large increase in the sludge index occurred at the lowest concentration. In the same table it is shown that the amount of dry solids in the sludge was more than doubled at the lowest concentration, while there was only a 10 per cent increase in solids at the highest concentration. This means that with a low sludge concentration a given amount of sugar will result in a greater amount of sludge accretion than a similar amount of sugar with a larger amount

of sludge. In other words, sludge bulking with sugar could be prevented either by decreasing the sugar concentration while holding the amount of sludge constant or by increasing the sludge concentration and holding the amount of sugar constant.

B. Effect of Sludge Condition upon the Rate of Bulking.—It has been shown that the material fed to activated sludge varied the rate of bulking, but this food factor did not seem to hold for each sample of sludge tested. The previous factors were studied upon separate samples and it was not always possible to check the results. The simultaneous study of two sludges under similar conditions gave the results shown in Table VIII. The Hillsdale sludge had a relatively high amount of nitrates and a good sludge index, the Madison-Chatham sludge had low nitrates and a rather poor index. When these two sludges were treated with a constant dose of glucose and varying amounts of urea-N to give C–N ratios of 16.6, 8.3 and 5.5 the number of doses to produce bulkiness varied. The two sludges bulked readily

TABLE VIII.—*Rate of Bulking of Different Sludges Under Similar Conditions*

Source of Sludge	Initial Condition of Sludge				Food Added			Sludge Condition After								
								4th Charge			7th Charge			22nd Charge		
	NO_3-N	Sludge Vol.	S.S.	Sludge Index	Glucose C	Urea N	C-N Ratio	Vol.	S.S.	Sludge Index	Vol.	S.S.	Sludge Index	Vol.	S.S.	Sludge Index
	P.p.m.	Per Ct.	P.p.m.		P.p.m.	P.p.m.		Per Ct.	P.p.m.		Per Ct.	P.p.m.		Per Ct.	P.p.m.	
Hillsdale	7.2	12	864	140	200	12	16.6	90	1295	695	—	—	—	—	—	—
"	"	"	"	"	"	24	8.3	—	—	—	58	1850	314	—	—	—
"	"	"	"	"	"	36	5.5	—	—	—	—	—	—	74	2730	270
Madison-Chatham	1.2	23	970	240	"	12	16.6	64	1500	425	—	—	—	—	—	—
" "	"	"	"	"	"	24	8.3	57	1390	410	—	—	—	—	—	—
" "	"	"	"	"	"	36	5.5	47	1390	340	—	—	—	—	—	—

(four doses) when dosed with the wide carbon nitrogen ratio, but with the lowest C–N ratios Hillsdale sludge required eighteen more doses to produce a bulky condition.

The addition of large amounts of urea together with sugar (low C–N ratios) permits nitrification. It would be possible that bulking could be correlated with the ability of a sludge to nitrify. To study this possibility, four sludges were adjusted as nearly as possible to the same sludge concentration. The nitrate content of the liquor was determined and 250 p.p.m. of ammonium bicarbonate added to each sample. The samples were aerated for six hours, the nitrate content of the liquors and the settling characteristics of each sludge determined at the sludge concentration studied. The results in Table IX show that the bulkiest of the four sludges had initially the most nitrates and produced the greatest amount of nitrates. The sludge with the lowest index produced the lowest nitrates. These results indicate that a sludge may be bulky and yet be able to nitrify ammonia. It should be stated that these results were obtained with an abundant air supply.

Although a bulky sludge may be able to nitrify, can the addition of nitrates alter the rate of bulking of sludge? A low sludge concentration (700 p.p.m. solids) was fed 600 p.p.m. glucose and 100 p.p.m. urea for eight doses. One sludge received only glucose and urea, while the other received in addition to glucose and urea 120 p.p.m. sodium nitrate at each change. The presence of the sodium nitrate did not prevent an increase in the sludge index, but retarded the increase. Initially the settling index was 44; after five feedings the index of the control was 290, while the one receiving nitrate was only 133; after three more

TABLE IX.—*Relation Between the Settling Index and the Nitrifying Power of Several Sludges*

Sludges	In Mixtures as Aerated			
	1	2	3	4
Susp. Solids, P.p.m.	1060	1275	1500	1904
Vol. of Sludge on Settling, Per Ct.	31	70	70	26
Sludge Index	290	550	465	135
NO_3–N Initially, P.p.m.	1.2	14	0.8	1.7
NO_3–N After 6 Hrs. Aeration, P.p.m.	14	32	15	14
Increase in NO_3–N, P.p.m.	12.8	18.0	15.0	12.0

charges the index of the control had increased to 770 while the sludge-fed nitrate had an index of 370.

The results given in Table IV indicated that nitrification can take place in the presence of glucose, but did not show whether or not nitrification is retarded by the presence of glucose. To clear up this point a portion of an activated sludge sample was dosed with 48 p.p.m. urea nitrogen and another portion with 48 p.p.m urea nitrogen and 600 p.p.m. glucose. The samples were aerated simultaneously for a period of six hours, and the procedure was repeated on a fill-and-draw basis for nine consecutive doses. At hourly intervals during the first, third and ninth doses nitrates were determined (Table X). During the initial dose

TABLE X.—*Effect of Sugar Upon the Nitrification of a Given Quantity of Urea*

Number of Doses	Initial Feeding		3rd Dose		9th Dose	
Hours Aeration	Control NO_3–N	Glucose NO_3–N	Control NO_3–N	Glucose NO_3–N	Control NO_3–N	Glucose NO_3–N
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Initial	2.6	2.6	4.0	2.8	4.4	9.6
1 hr.	3.2	3.6	4.0	7.2	11.0	11.0
2 hr.	5.6	6.0	4.5	9.6	—	—
3 hr.	—	—	—	—	24	24
4 hr.	—	—	—	—	28	23
5 hr.	—	—	8.8	20.0	32	24
6 hr.	13.0	13.0	14.4	24.0	36	26

both the rate of nitrification and the amount of nitrates produced from urea with and without glucose were practically the same. During the third dosing period the sludge with glucose nitrified at a higher rate and produced more nitrates than urea alone. During the ninth dose the relationship was somewhat reversed. In view of the generally accepted view that the presence of available carbohydrates retards nitrification these results are noteworthy. The commonly held view may be explained on the basis of the following facts: (1) retardation of nitrification may be due to a limitation of nitrogen set up by the excess of carbohydrates, (2) the amounts of sugar used to bring about the depressing action are higher than employed in these experiments. That with a limited amount of nitrogen, the nitrogen will be used preferentially for sugar metabolism has already been demonstrated by the results given in Table IV, but when allowance is made for the amount of nitrogen required for the utilization of the sugar and an excess of nitrogen is added beyond this requirement, there will be no retardation of nitrification, as demonstrated in this experiment.

The results presented in Tables VIII and IX appear contradictory and may seem to invalidate the statement that the stage of oxidation of a sludge (as indicated by the amount of nitrate) has an important bearing on the rate of bulking of sludge. In other words, sludges obtained at random from different plants with various methods of operation, different amounts of air application, dissimilar detention periods, nonhomogeneous sewage and changes in strength, together with several other variables, the amount of nitrates may not be a true picture of the stage of oxidation of a sludge. It was therefore necessary to determine this point with a single non-nitrifying sludge, inducing nitrification under laboratory conditions and testing the response to sugar. A nonnitrifying sludge was divided into three portions: one part was aerated immediately with sugar at three different C–N ratios; a second part was aerated with two doses of sewage for two 6-hour periods on a fill-and-draw basis; the third portion was similarly treated with sewage for a period of three days. The sewage treated samples were tested for nitrates, suspended solids, and settling index. The mixtures were settled and the sludge treated with sugar at different C–N ratios similar to the initial sample. The aeration of activated sludges under laboratory conditions produced highly oxidized, well settling, highly nitrifying sludges. Thus, the sludge index dropped from 270 to 150 with eleven sewage additions, while the nitrate content of the liquor rose from zero to 19.0 p.p.m. (Table XI). The better settling, more highly nitrifying sludge was more difficult to bulk than the sludge obtained directly from the plant. As the sludge became more difficult to bulk it also became more sensitive to the nitrogen (ammonia) content of the liquor in its rate of bulking.

In a well oxidized sludge, as indicated by the relatively high amount of nitrates, the amount of raw material accumulated over a period of time from sewage should be lower than in a sludge not so well oxidized. B.O.D. determinations show within wide limits the degree of oxidation

TABLE XI.—*Effect of Sludge Condition on the Bulking of Activated Sludge*

		Sludge as Obtained				Sludge After 2 Doses of Sewage				Sludge After 11 Doses of Sewage			
Sludge Index....				270		350				150			
Ini. NO_3-N, P.p.m.				0.0		0.8				19.0			
Ini. S. S., P.p.m..				586		400				534			
Material Fed		Doses	Vol. of Solids	Susp. Solids	Sludge Index	Doses	Vol. of Solids	Susp. Solids	Sludge Index	Doses	Vol. of Solids	Susp. Solids	Sludge Index
Glucose C	Urea N												
P.p.m.	P.p.m.	No.	Per Ct.	P.p.m.		No.	Per Ct.	P.p.m.		No.	Per Ct.	P.p.m.	
200	12	5	83	1425	580	8	62	1545	400	10	68	1840	370
"	24	"	73	1410	520	8	61	1500	405	15	86	2420	360
"	36	"	40	1320	300	27	26	3925	70	18	58	2665	220

of sludge (3). Ruchhoft and Smith (11) have also developed a method which determines the stage of oxidation of sludge. Yet there is no readily available and accurate method of differentiating between the raw material accumulated in the sludge and the more highly oxidized matter in the sludge. In addition, differences in the type of flora may also exist in well and poorly oxidized sludges. If, as the sludge becomes well oxidized, it undergoes simultaneously changes in the constitution of the flora such as a relative drop in the numbers of *Sphaerotilus*, then the addition of small amounts of a bulky sludge containing *Sphaerotilus* to a non-bulky sludge should stimulate the rate of bulking. Although there is no method of measuring directly the relative numbers of zoogleal organisms and *Sphaerotilus*, an indirect method to indicate the relative importance of the different numbers of each was attempted. A sample of activated sludge was divided into four portions; two were dosed with sewage and two with 500 p.p.m. sugar at a C–N ratio of 20. One of each series was left as control while the other received 5 per cent by volume of a bulky sludge. The aeration was continued on a fill-and-draw basis for four charges. The results show (Table XII) that in-

TABLE XII.—*Effect of a Bulky Seed Upon the Rate of Bulking of a Non-bulky Sludge*

Material Fed	Bulky Sludge Used as Seed	Sludge Index		Susp. Solids	
		Initial	Final	Initial	Final
				P.p.m.	P.p.m.
Sewage.....	Absent	121	108	1107	1300
Sewage.....	Present	128	107	1290	1400
Sugar + Urea *.....	Absent	122	180	1147	1570
Sugar + Urea *.....	Present	129	510	1240	1720

* Four charges of 500 p.p.m. sugar and 10 p.p.m. urea N.

oculation with a bulky sludge did not increase the sludge index when the sludge was dosed with sewage, but caused an increase in the sludge index of the sludge treated with glucose and urea.

Discussion

Activated sludge may be bulky due to any of at least three different reasons: (1) bulky sludge may have a slightly lower specific gravity than a non-bulky sludge, which would decrease its rate of settling; or (2) the floc surfaces of a bulky sludge may have a different chemical structure, which causes a greater hydration of the floc and thus retards its flow through water; or (3) the floc may undergo mechanical changes in its structure retarding settling. The Committee on Sewage Disposal of the American Public Health Association in its 1937 report (9) on "Bulking of Activated Sludge," recognized two types of bulking: (1) "Flocculated sludge with a high index and low settling rate. This is usually accompanied by a high volatile content and frequently occurs in dry weather. Overloading may also be a factor. (2) Slimy deflocculated sludge, with an extremely low rate of settling. This is usually accompanied by vigorous growths of *Sphaerotilus* and the presence of carbohydrate wastes." The first type of bulking as noted in the Committee Report might be the result of either of the first two causes of bulking indicated above, while the second type of bulking would be brought about predominantly by a change in the mechanical structure of the floc.

A change in the chemical composition of the floc caused by an increase in the fat content, which lowers the specific gravity of the floc particles, may decrease the rate of settling. An accumulation of fat will take place if the organisms have access to an excess of food for energy and growth. Many investigators have concluded that bulking may be the result of a lack of oxidation of the food in the sewage. Our results failed to give any evidence of a materially higher fat content in bulky sludges. These results are at variance with Jenkin's (6) statement that sugar fed to trickling filters resulted in clogging and accumulation of fats in the filter film. The fats increased up to 10 per cent when the filter was supplied with sugar and an available source of nitrogen, such as ammonium sulfate and ammonium carbonate.

The amounts of air used in laboratory experiments handling small volumes of sludge mixtures are relatively high and thus might explain why under such conditions fats do not accumulate when activated sludge is supplied with carbohydrates and an available source of nitrogen. In spite of the failure of fat accumulation the sludge bulked and it is difficult at present to see a direct relation between bulking and fat content. If a change in the specific gravity is the fundamental difference between a bulky and a non-bulky sludge, the fats are not the cause.

Our early work indicated that certain substances produced bulking of activated sludge rapidly, while other substances did not produce bulking. Glucose when added with sewage to sludge induced a rapid bulking while a quantity of peptone with an equivalent amount of carbon, under similar conditions, did not produce bulking. Since peptone contains 15 per cent nitrogen, it was thought that the nitrogen might be the cause for the failure of the peptone to cause bulking of the sludge. This was found to be partially true, inasmuch as at a

given sludge and sugar concentration the amount of nitrogen added greatly affected the rate of change of the sludge index. The amounts of nitrogen added, which were insufficient for complete utilization of the sugar, permitted the sludge to bulk rapidly, while the settling index increased very much more slowly when just enough nitrogen was added. When more than an adequate amount of nitrogen was added, nitrates were formed. The formation of nitrates required oxygen and this utilization of oxygen might have accounted for the higher sludge indices when more than enough nitrogen was present (Fig. 1). When, however, amounts of sugar and urea that permitted a slow increase in the sludge index were fed to a lower concentration of sludge, the sludge index rose sharply. When the sludge concentration was high enough, the settling index did not increase materially.

In order to illustrate more clearly the relation between the amount of sugar added and sludge concentration, the results in Tables VI and VII are recalculated and expressed on the basis of grams of sugar added per gram of sludge. These computations are presented in Table XIII. It will be seen that the higher the amount of sugar per unit

TABLE XIII.—*Relation Between Quantity of Sugar, Amount of Sludge and Bulking*

Expt.	Sugar Fed	Suspended Solids	Ratio Sugar/Sludge	Doses	Increase in Sludge Index	Increase in Solids
No.	P.p.m.	P.p.m.		No.		P.p.m.
6	31	540	0.06	13	−32	52
6	63	"	0.11	13	−19	145
6	125	"	0.23	13	43	420
6	250	"	0.46	12	156	700
6	500	"	0.92	6	230	650
7	600	3100	0.20	3	11	340
7	"	1250	0.48	3	50	485
7	"	470	1.28	3	116	620

amount of sludge the more rapidly and the more severely the sludge bulked. With very low sugar-sludge ratios the increase in the sludge index was either slight or there was an actual decrease. Retardation of bulking could be accomplished either by decreasing the sugar and keeping the initial sludge concentration constant or by keeping the amount of sugar constant and increasing the sludge concentration. It should be remembered that these ratios are based only on the initial sludge concentration, which considerably increased during the dosing period. The table also shows that the increase in the amount of sludge is dependent on the sugar-sludge ratio. The higher this ratio the greater the increase in the amount of sludge. In other words, when the concentration of sugar in relation to the sludge is high there is a more rapid building up of sludge by synthesis than when the ratio is low. That this is not necessarily due to the lower amount of sugar

added is illustrated in the second part of the table, where, with a constant amount of sugar added, the amount of sludge formed was less, even with higher sludge concentration. In other words, whenever the amount of food added in relation to the sludge is low, the net increase in the weight of sludge will be low, because after the added food is utilized, the organisms will act upon the sludge itself.

A note of warning should be sounded here against too ready an application of these results obtained under laboratory conditions to similar phenomena in plant operation. Specifically, the actual concentrations of sugar and sugar-sludge ratio causing bulking observed under laboratory conditions may not be directly applicable to plant operation. One reason is the discrepancy which exists in the air applied per unit volume between laboratory and plant conditions. The actual concentrations and sugar-sludge ratios that produce bulking under plant operation may be lower than those observed in these studies.

The facts cited bear out the empirical conclusion arrived at by certain operators that carrying large quantities of sludge in the aeration tanks is a good precaution, to serve as a cushion against the detrimental effects brought about by the sudden discharge of large amounts of waste. Large concentrations of sludge in the presence of large quantities of organic wastes will, however, tax the aeration system and may not prevent the ultimate bulking of the sludge.

Thus far the studies have indicated two factors which influenced bulking: (1) The larger the quantity of sugar in relation to the sludge concentration, the more quickly the bulking; (2) the quantity of nitrogen in relation to the carbon of the sugar is important in the rate of bulking at certain sludge-sugar ratios.

Nitrogen in its various forms may be important both as an indicator of the sludge condition and as part of the material needed for new protoplasm. One of the best indices of a well oxidized sludge is the presence of nitrates in the sludge liquor. In the presence of carbohydrates, ammonia is essential for developing new protoplasm.

The results presented show that the rate of change from a nonbulky to a bulky sludge could be retarded by the presence of sodium nitrate, but that the bulking was not prevented. The retarding influence of nitrates on bulking cannot be attributed to the reduction of nitrates, with utilization of oxygen, since aeration was ample to bring about the formation of nitrates. The presence of 600 p.p.m. sugar did not alter the rate of nitrate formation when there was an adequate supply of ammonia, so that the excess of ammonia, which was transformed to nitrates, may have exerted part of its influence in preventing bulking through the subsequent formation of nitrates.

What part do nitrates play in the condition of activated sludge? It is the opinion of the authors that the nitrates indicate the degree of oxidation of the sludge, but that a poorly oxidized sludge may produce nitrates when vigorously aerated. It has been shown by Lockett (7) that periods when the sludge is dense correspond to periods of substantial amounts of oxidized nitrogen.

The theory underlying the changes between a non-bulky and bulky sludge has intrigued many workers. The idea has been expressed by Haseltine (2) that bulking is due to a lag in the oxidation of the absorbed materials, or in other words, that the overloading of the sludge causes bulking. Our results confirm the hypothesis that overloading is a cause of bulking, but why should overloading of sludge cause bulking? Is 600 p.p.m. of sugar with 40 p.p.m. of urea more of a load than 600 p.p.m. of sugar with 100 p.p.m. of urea? Yet the former combination will cause bulking while the latter combination will not.

Does overloading or the addition of excess carbonaceous materials bring about a change in the activated sludge floc through changes in the settling properties of zoogleal organisms? Heukelekian and Littman (4) have shown that overloading, or the addition of carbonaceous materials with limited nitrogen, does not cause any difference in the settling index of pure culture sludge of zoogleal organisms. However, both overloading with sugar alone, or with sugar and a limited amount of nitrogen, bring about a rapid growth of *sphaerotilus*. Bulking is, therefore, produced by those conditions which are more favorable to *sphaerotilus* than to zoogleal organisms. *Sphaerotilus* and zoogleal organisms are normally present in activated sludge and they are in a continuous struggle for existence and for food. When *sphaerotilus* is predominant, a sludge is bulky and when a sludge settles well, it is predominantly composed of zoogleal organisms.

If zoogleal organisms cannot be made to bulk, what is the meaning of the two types of bulking identified by the Committee of the American Public Health Association? We conclude that the two types mentioned in the Committee report (9) are different in degree and not in kind. Observation of young cultures of *sphaerotilus* show that they look very much like zoogleal organisms and it is possible that the diffuse, light-floc particles are caused by the growth of *sphaerotilus* within the floc. The *sphaerotilus* in Fig. 7 of Smit's paper (14) illustrates this point and is very characteristic of some of the less bulky sludges. Such a growth might readily be taken for zooglea by the unskilled worker.

The physiology of these two organisms is very different. In the first place, zoogleal organisms are strict aerobes and although they fail to grow under anaerobic conditions, lack of oxygen does not kill them (1). *Sphaerotilus,* on the other hand, can grow both under anaerobic or aerobic conditions, and Smit (14) states that aeration during incubation results in a marked retardation of development. In the second place, zoogleal organisms grow very slowly (1) while *sphaerotilus* grows rapidly (14). A high concentration of food favors and is required for the growth of *sphaerotilus* (14) while zoogleal organisms grow quite readily in a dilute medium such as sterile sewage (1).

Finally, for a given amount of nitrogen, *sphaerotilus* is capable of utilizing several times as much sugar as the zoogleal organisms. This concept is a necessary conclusion of the evidence presented in the experimental part, wherein it was repeatedly demonstrated that with an ample supply of sugar but a limited supply of nitrogen bulking de-

veloped rapidly and *sphaerotilus* predominated. Furthermore, under such conditions (ample supply of sugar and limited supply of nitrogen) the rate of sugar utilization was accelerated with each succeeding dose until a maximum rate was reached. At this stage *sphaerotilus* became established and severe bulking occurred.

With these three fundamental concepts of differences in the physiology of these activated sludge organisms, we can readily follow the course of events when activated sludge bulks with sugar additions.

With a deficient amount of nitrogen the development of zoogleal organisms is limited to the amount of nitrogen present. The development of *sphaerotilus,* on the other hand, is favored by the excess of sugar left in solution and as this organism becomes established it competes favorably with the zoogleal organism for the available food.

The interior of the floc is an excellent locus for the initial development of *sphaerotilus,* because less oxygen will diffuse into the center of the floc. As the oxygen is reduced (12) the presence of food will make conditions more favorable for *sphaerotilus* than for the zoogleal organism.

A high concentration of sugar can diffuse into the center of the floc and will provide the necessary energy for the growth of *sphaerotilus.* As the *sphaerotilus* grows, the floc will become somewhat light and expanded and the sludge will become slightly bulky. At this stage, filaments of *sphaerotilus* may or may not be visible. If this condition is not arrested, a heavy overgrowth of *sphaerotilus* will bring about severe bulking. When the sludge is bulking the filaments of *sphaerotilus* can be readily seen, growing out of the floc and extending some distance beyond. The initial condition can be overcome with an abundant supply of oxygen and a small quantity of food (which is needed for the growth of zooglea), but the severe condition of bulking can be corrected only with the greatest difficulty and many operators prefer to start over with a new sludge.

Although glucose favors bulking, equivalent amounts of peptone do not induce bulking. Glucose or other carbohydrates are readily available for energy while peptone and proteinaceous materials are much less available for most microorganisms. Peptone was not utilized as rapidly as the sugar and was present in the liquor after several feedings. Since its energy is not readily available for growth, it does not favor *sphaerotilus.* The floc became very dense under the microscope when peptone was fed and there was no evidence of *sphaerotilus,* although this organism might have been present in the altered form mentioned previously (14). These facts indicate that the type as well as the quantity of food is important in the bulking of activated sludge.

Realizing that the relative numbers of *Sphaerotilus* and zoogleal organisms largely determine the rate of bulking induced by a given food, it is not surprising that the condition of the sludge and the seeding of a non-bulky sludge are important factors. The seeding of the non-bulky sludge with a bulky sludge increased the relative numbers of *sphaerotilus,* while the aeration of a slightly bulky sludge with sewage

under laboratory conditions induced oxidation and probably reduced the relative numbers of *sphaerotilus*. The time to produce bulking was increased with the reduced numbers of *sphaerotilus*, while the time was decreased when the numbers were increased artificially and the conditions for their development were made favorable by an excess of sugar. When the numbers of *sphaerotilus* were increased by inoculation of non-bulky sludge with bulky sludge, the mixture did not bulk when it was fed with sewage.

The factors considered are probably not the only ones involved in the bulking of activated sludge. Although neither glucose nor nitrates gives a true oxidation-reduction potential, approximate values can be obtained. Glucose will reduce dyes of a potential higher than —0.2 volt on the oxidation-reduction scale and will not reduce dyes of a lower potential. Although nitrates are very stable, only materials with a potential of at least +0.3 can bring about their formation. Can the low potential of the glucose favor the growth of *sphaerotilus* while the nitrates through their higher potential depress the growth? This problem will be discussed in a following paper. Bulking is the result of the successful invasion by a facultative anaerobic organism over an aerobic organism, so that the smaller the quantity of oxygen present the more rapid the bulking. Results on the role of oxygen in relation to bulking will be presented in a subsequent paper.

Summary

Laboratory experiments were conducted by dosing activated sludge with various carbonaceous and nitrogenous materials on a fill-and-draw basis to determine the effect of the following factors on the rate of bulking:

1. The possible synthesis of fats from various non-fatty carbonaceous materials and the relation of the fat content to the bulkiness of the sludge.
2. The addition of several different nitrogenous materials with sugar and the addition of varying concentrations of urea with sugar.
3. Correlation with changes in the rate of utilization of sugar and urea with repeated feedings, while varying the amounts of sugar.
4. The relation of the amount of sugar added to the sludge by varying both.
5. The character of the sludge as determined by nitrifying power as well as the initial nitrate content of the sludge.
6. Seeding with small amounts of a bulky sludge on the rate of bulking of a sludge fed with (*a*) sewage and (*b*) sugar and urea.

The facts obtained from these various studies are interpreted on the basis of the differences in the physiology of *sphaerotilus* and zoogleal organisms.

Conclusions

1. Bulking induced by the addition of glucose or starch to activated sludge did not result in a higher fat content of the sludge.

2. The fine particles of floc going over the weir are not necessarily higher in fat content than the sludge that remains in the bottom of the settling tank.

3. The addition of sufficient supply of available nitrogenous materials such as urea, ammonium bicarbonate, ammonium chloride, etc. results in retardation of bulking. The optimum amount of nitrogen is such that will permit the rapid utilization of glucose and will leave a slight excess for nitrification. The optimum value to meet the above requirements, expressed as C–N ratio of the sugar and nitrogenous material, is approximately 8. With little or no additions of nitrogen, sludge does not bulk readily because of the inability of the organisms to utilize the glucose.

4. The concentration of the glucose is an important factor. When the amount of glucose added is small there will be little if any increase in the sludge index. As the amount of glucose is increased, the rapidity and the violence of bulking will also increase. Sludge concentration is an important factor in bulking induced by sugar. The higher the sludge concentration the less rapidly and violently will the sludge bulk. There is a definite sugar-sludge ratio for maximum sludge bulking.

5. The condition of the sludge has an important bearing on the rate of bulking. A highly nitrified sludge will bulk less readily with certain sugar and nitrogenous material dosages than the same sludge in a less nitrified condition.

6. The addition of glucose up to 600 p.p.m. has little if any effect on the rate of nitrification of urea, provided the amount of urea added is in excess of the nitrogen requirements set up by the glucose.

7. The inoculation of a non-bulky sludge with a small quantity of a bulky sludge results in the acceleration of the rate of bulking, provided the sludge is dosed with glucose, but the sludge index is unaltered when the sludge is dosed with sewage.

Bulking produced by carbohydrates is a direct response of *sphaerotilus* to a relatively long contact with an available energy food. The concentration of glucose must be high enough in relation to the sludge concentration to produce this response. Under laboratory conditions the relationship of air to sludge-mixture volume is high and minimum concentration of glucose to create the development of *sphaerotilus* will be high. When there is a limited amount of nitrogen in the presence of glucose, zoogleal organisms cannot completely utilize the glucose, leaving an excess to stimulate the growth of *sphaerotilus*. If there is no nitrogen added, neither the *sphaerotilus* nor the zoogleal organisms will develop extensively. When there is an abundance of nitrogen in the presence of fairly large amounts of glucose, the zoogleal organisms can compete with *sphaerotilus* only for a short time; *sphaerotilus* develops at a much higher rate in the presence of glucose than zoogleal

organisms, so that the final predominance of *sphaerotilus* even in the presence of abundant supply of nitrogen cannot be prevented. The condition of the sludge, defined as the stage of oxidation of the sludge and indicated by the nitrate content, plays an important part in the bulking produced by the addition of sugar. This factor might exert its influence through: (1) a shift in the flora such as a decrease of numbers of *sphaerotilus* in well oxidized sludges (2) oxidation-reduction phenomenon.

These generalizations are based on the following facts: (1) that zoogleal organisms cannot be made to bulk under conditions which readily induce sludge bulking (2) zoogleal organisms are strict aerobes while *sphaerotilus* is a facultative anaerobe.

References

1. C. T. Butterfield, "Studies of Sewage Purification. II. A Zooglea-Forming Bacterium Isolated from Activated Sludge," *Pub. Health Repts.*, **50**, 671 (1935).
2. T. R. Haseltine, "The Activated Sludge Process at Salinas, California, with Particular Reference to Causes and Control of Bulking," *This Journal*, **4**, 461 (1932).
3. H. Heukelekian, "Effect of Aeration on the Rate of Oxidation of Activated Sludge," *This Journal*, **6**, 897 (1934).
4. H. Heukelekian and M. L. Littman, "Carbon and Nitrogen Transformations in the Purification of Sewage by the Activated Sludge Process. II. Morphological and Biochemical Studies of Zoogleal Organisms," *This Journal*, **11**, 752 (1939).
5. R. S. Ingols and H. Heukelekian, "Buffer Values of Sewage During Purification," *Ind. Eng. Chem.* (In press, 1939).
6. S. H. Jenkins, "The Treatment of Waste Waters from Dairies," *Inst. of Sewage Purif., Jr. and Proc.*, Part II, 13 (1937).
7. N. T. Lockett, "A Contribution to the Literature Relating to the Activated Sludge Process," *Inst. of Sewage Purif., Jr. and Proc.*, Part II, 88 (1937).
8. F. W. Mohlman, "The Sludge Index," *This Journal*, **6**, 119 (1934).
9. L. Pearse, Committee Chairman, "Bulking of Sludge in the Activated Sludge Process of Sewage Treatment," *Amer. Pub. Health Assoc. Year Book, Supplement to Jr.*, **27**, 164 (1937).
10. J. P. Peters and D. D. Van Slyke, "Quantitative Clinical Chemistry," Vol. 2, Methods, The Williams and Wilkins Co., Baltimore (1932).
11. C. C. Ruehhoft and R. S. Smith, "Studies in Sewage Purification. X. Changes in Characteristics of Activated Sludge Induced by Variations in Applied Load," *This Journal*, **11**, 409 (1939).
12. L. R. Setter, "A Rapid Determination of Suspended Solids in Activated Sludge by the Centrifuge Method," *This Journal*, **7**, 23 (1935).
13. J. Smit, "A Study of the Conditions Favoring 'Bulking' of Activated Sludge," *This Journal*, **4**, 960 (1932).
14. J. Smit, "Bulking of Activated Sludge. II. On the Causative Organisms," *This Journal*, **6**, 1041 (1934).

ACTIVATED SLUDGE OXIDATIONS

IV. THE INFLUENCE OF TEMPERATURE UPON THE RATE OF OXYGEN UTILIZATION BY ACTIVATED SLUDGES

By Clair N. Sawyer and Gerard A. Rohlich

Laboratories of Hydraulic and Sanitary Engineering, University of Wisconsin, Madison, Wis.

The operation of sewage treatment plants is usually a year-round proposition. In temperate zones the fluctuation in sewage temperatures with seasonal climatic conditions is considerable and it is common for plant records to show variations of 15° C. from the extremes of late summer to those of late winter. The extent of the influence which such temperature changes have upon biological methods of sewage treatment has not been widely recognized.

Sawyer and Nichols (1) have shown from their studies on a single activated sludge that the rate at which oxygen was being used at 25° C. was approximately four times as rapid as at 10° C. In an attempt to explain the usually normal operation of most plants during the winter months, they suggested that perhaps in actual practice a compensatory factor intervenes during winter operating conditions to overcome the effect of the lowered temperatures. It does not seem probable that such self-compensation could be complete within itself. Thus, it appears that, in view of the magnitude of the temperature factor, the effect of temperature on the rate of stabilization of sewage should be considered in determining the quantity of aeration solids to be maintained for efficient, economical, and uniform operation.

Laboratory control of activated sludge plants has been recognized as a necessity since the first applications of the process. Various tests and observations are in use which give the plant operator or chemist a means of control in operation and a picture of how his plant can be expected to function in the immediate future. A recent development which appears to offer much promise is the practice of determining the characteristics of activated sludges by studying their rates of oxygen utilization either before or after having been fed. Such studies are somewhat complicated by the necessity of carrying on the laboratory work under controlled temperatures which must be similar to and varied with the seasonal changes which occur in the plant itself. It is felt that knowledge concerning the effect of temperature variations on the rate of oxygen usage will be of practical value in providing a means of interpreting the results obtained in the laboratory at one temperature, in terms applicable to conditions actually present in the plant.

In a previous paper, Sawyer and Nichols (1) have reviewed the work published by several investigators and have reported the results of their investigations on the effect of temperature upon the rate of oxygen utilization by activated sludges. Their data could not be correlated with the conclusions of Viehl (2) who stated that his results

indicated that the rate of carbonaceous oxidation was only slightly affected, if at all, by temperature changes, while the rate of nitrogenous oxidation was greatly affected, being increased two or three times for an increase of 10° C. in accordance with the law advanced by van't Hoff.

The objectives of the investigation herewith presented are threefold: (1) to determine the influence of temperature on the rate of oxygen utilization by activated sludges and activated sludge-sewage mixtures from several plants when subjected to both summer and winter conditions, (2) to determine the influence of temperature on the rate of oxygen utilization by activated sludges produced under summer and under winter conditions, and (3) to determine the influence of temperature on the rate of oxygen utilization as carried on by nitrifying organisms and as carried on by those organisms that stabilize carbonaceous material.

Sources of Activated Sludges and Laboratory Methods

Activated sludges and sewages used in this investigation were obtained from four Wisconsin cities. In general the samples were collected at the sewage treatment plants during the morning and transported immediately to the laboratory by automobile. Upon arrival at the laboratory, oxygen utilization studies were made simultaneously at 10, 15, 20 and 25 deg. C. on identical mixtures of activated sludge and sewage from a particular source. Activated sludge in excess of the needs for such runs was always obtained. This was kept well aerated without feeding, until the following day at which time base rate determinations of oxygen utilization were made. In addition to obtaining data on temperature coefficients for use in plant operation and control it was felt that the studies on fed and unfed sludges would yield information showing whether or not the rates of nitrogenous and carbonaceous oxidations were influenced differently by temperature changes. Sawyer (3) has shown that with an actively nitrifying sludge the high rate of oxygen usage obtained immediately after feeding was in a great part due to oxidation of nitrogen, and, when the demand for oxygen dropped to its low level or base rate, carbonaceous oxidation was the principal factor involved.

To determine whether or not the effect of temperature on the rate of oxygen utilization of activated sludge might vary with the season of the year, studies were made on all four sludges obtained under the operating conditions of extreme summer and winter temperatures. Determinations of oxygen utilization by each activated sludge at the four temperatures previously mentioned (10, 15, 20, and 25 deg. C.) were made simultaneously using four Oxy-Utilometers. Data of a chemical nature were obtained by procedures outlined in *Standard Methods of Water Analysis* (1936).

Experimental Results

The results of the studies showing the effect of temperature upon the rate of oxygen utilization by the various activated sludge-sewage

mixtures is shown in the series of Graphs 1 to 8 inclusive. Inspection of these graphs will show that in general the effect of temperature variations is approximately the same with each sludge regardless of whether the sludges were accustomed to winter or summer temperatures. The shape of the oxygen utilization rate curves are of two general types, namely those which show a definite break in the rate and those which do not. A comparison of the effect of temperature on the rate of oxidation may easily be made in the case of the sludges producing sharp breaks (Graphs 1, 2, 3, 5, 7), since it is necessary to take only average or representative values from the curves prior to the time the break occurs. In the case of the rate curves which do not show a definite break (Graphs 4, 6, 8), there seems to be no certain way of obtaining values which represent identical stages of oxidation.

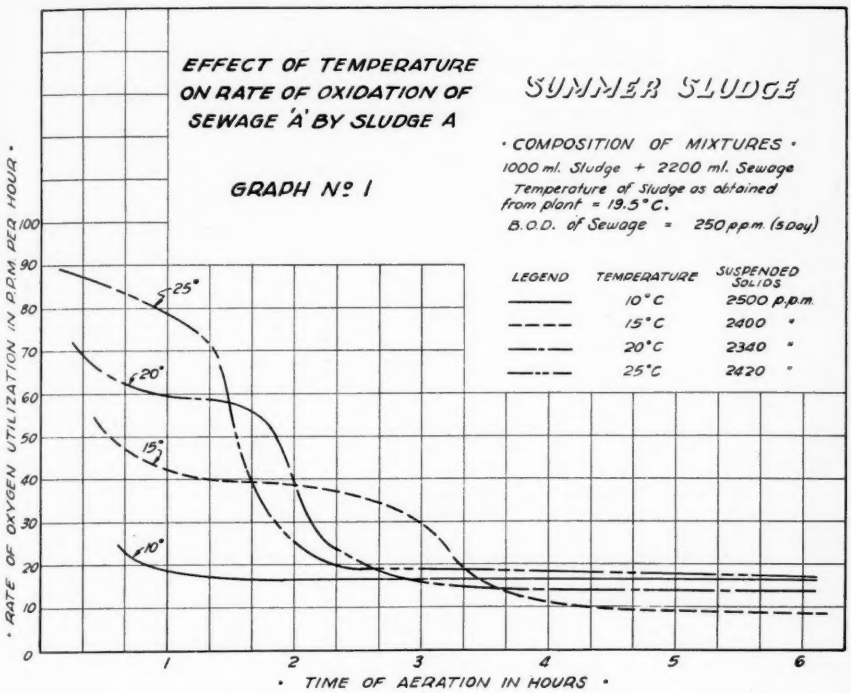
A correlation of the effect of temperature on the maximum rate of oxygen utilization by those activated sludge-sewage mixtures producing definite breaks in the curve is shown in Fig. 1. The data taken from the graphs has been adjusted to a uniform basis of one gram of dry sludge in order to make the curves of Fig. 1 directly comparable. In general the curves appear to be straight lines which indicates that the temperature coefficient of oxygen utilization is essentially constant over the range studied. Because of the difficulty in selecting rate values which will represent identical stages of oxidation even when sharp breaks occur in the curves, the authors consider that the values chosen from the data on sludge-sewage mixtures (Graphs 1–8) are less reliable than those obtained from the base rate data on sludges alone which usually produce nearly horizontal rate curves.

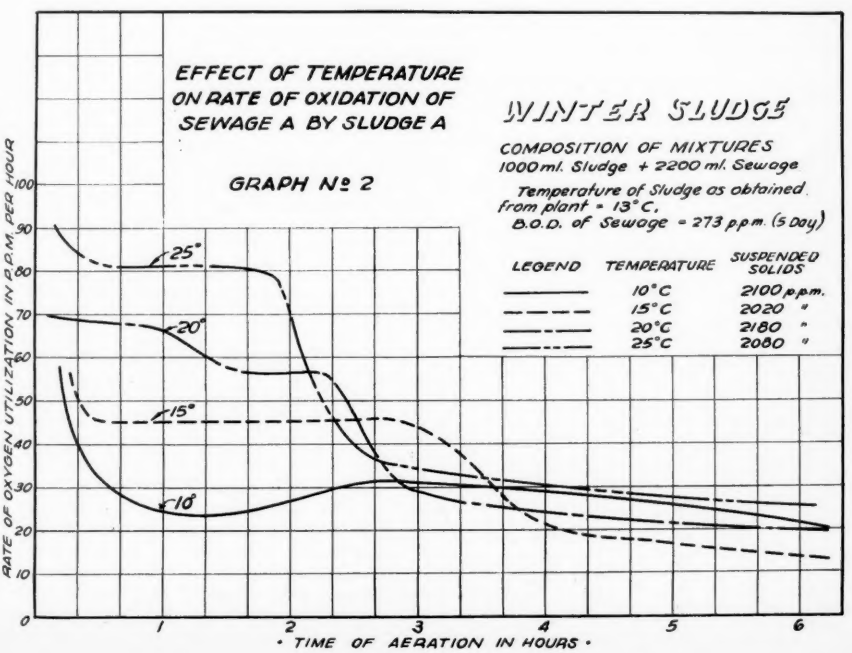
In Table I, the data shown in Fig. 1 are presented on a percentage basis in order to show their numerical relationship. In this table the

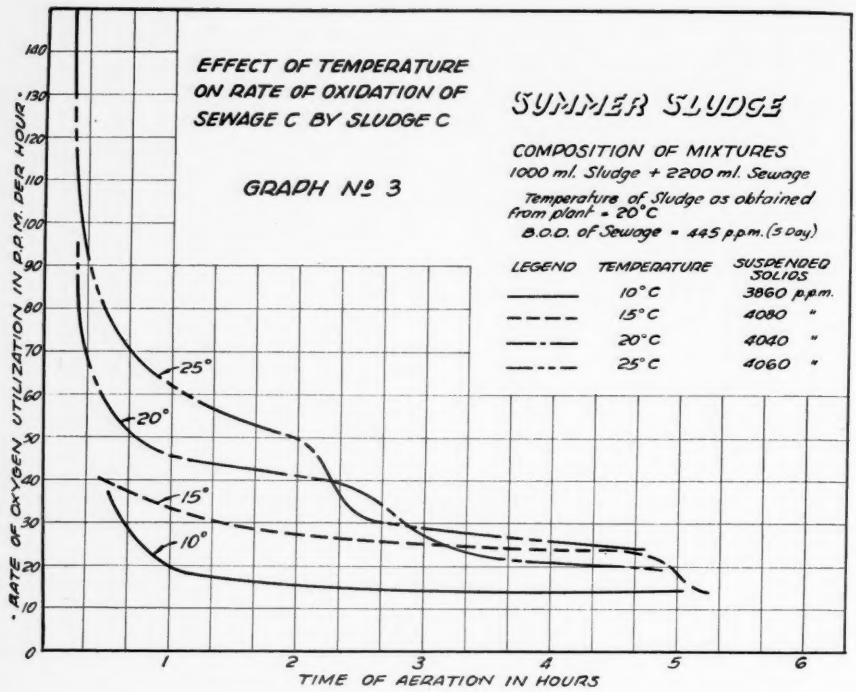
TABLE I.—*Relative Rates of Oxygen Utilization by Various Activated Sludge-Sewage Mixtures Expressed in Per Cent. Based on Value at 25° C. = 100%*

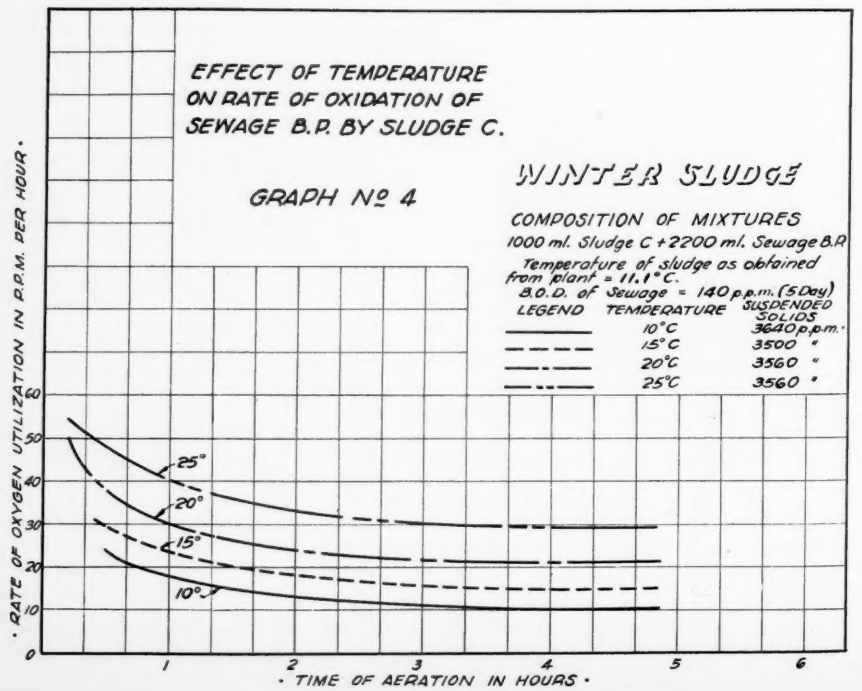
Source of Activated Sludge-Sewage Mixture	Temperature, Centigrade							
	25°		20°		15°		10°	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
A	100	100	76.1	73.1	49.6	56.9	21.5	33.3
C	100	—	71.8	—	42.1	—	25.6	—
D	100	—	69.2	—	44.8	—	22.6	—
E	100	—	76.3	—	48.0	—	26.4	—
Seasonal Average	100	100	73.35	—	46.1	—	24.0	—

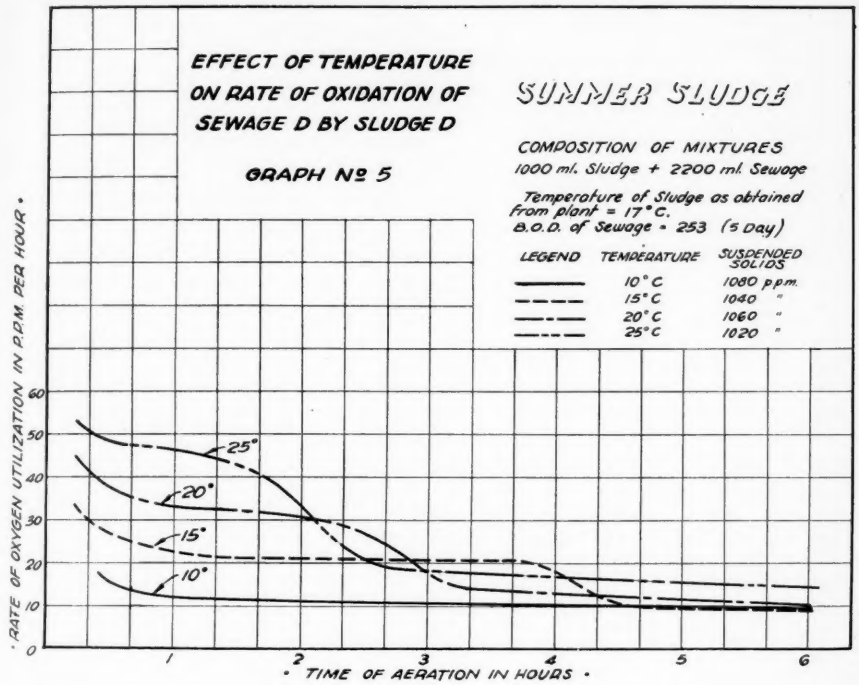
rate of oxygen usage obtained for each sludge at 25° C. is given a value of 100 per cent and the values obtained at the other temperatures are rated accordingly. The table shows that the rates for the various sludges at 20, 15, and 10 deg. C. average approximately 73.4, 46.1 and

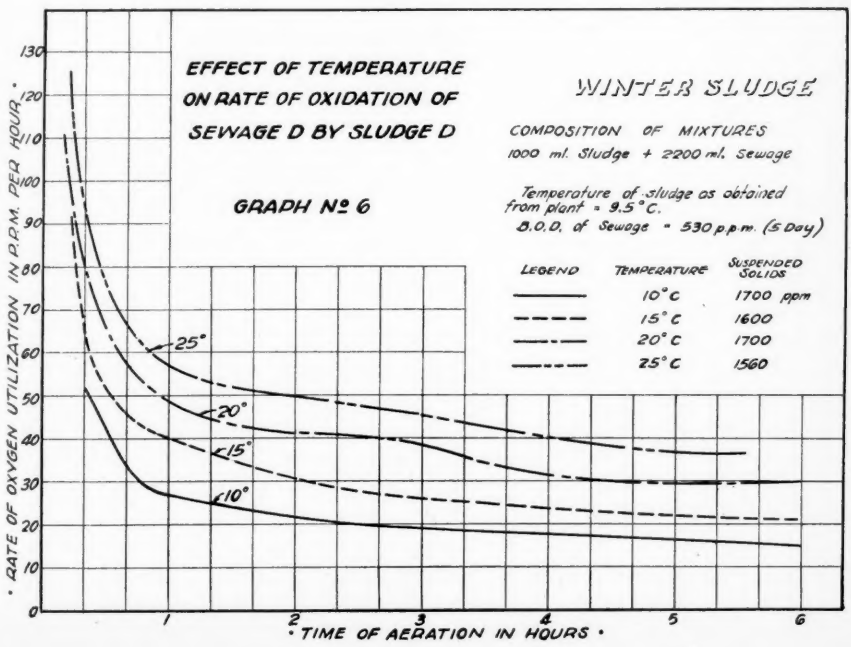

EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE 'A' BY SLUDGE A
GRAPH Nº 1
SUMMER SLUDGE
· COMPOSITION OF MIXTURES ·
1000 ml. Sludge + 2200 ml. Sewage
Temperature of Sludge as obtained from plant = 19.5°C.
B.O.D. of Sewage = 250 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 2500 p.p.m.
15°C 2400 "
20°C 2340 "
25°C 2420 "
25°
20°
15°
10°
· RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR ·
· TIME OF AERATION IN HOURS ·

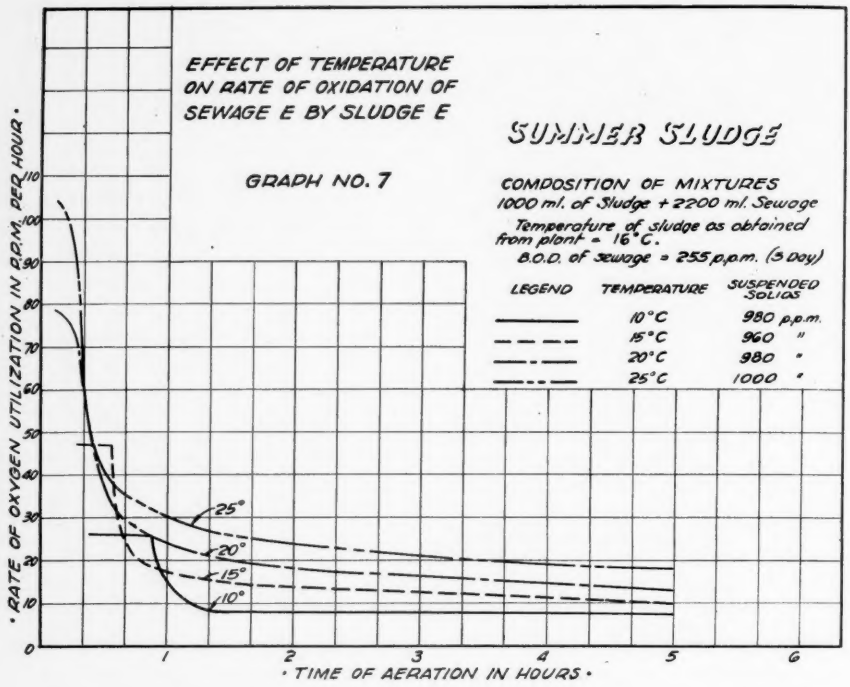

EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE A BY SLUDGE A
GRAPH Nº 2
WINTER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge + 2200 ml. Sewage
Temperature of Sludge as obtained from plant = 13°C.
B.O.D. of Sewage = 273 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 2100 p.p.m.
15°C 2020 "
20°C 2180 "
25°C 2080 "
25°
20°
15°
10°
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
· TIME OF AERATION IN HOURS ·

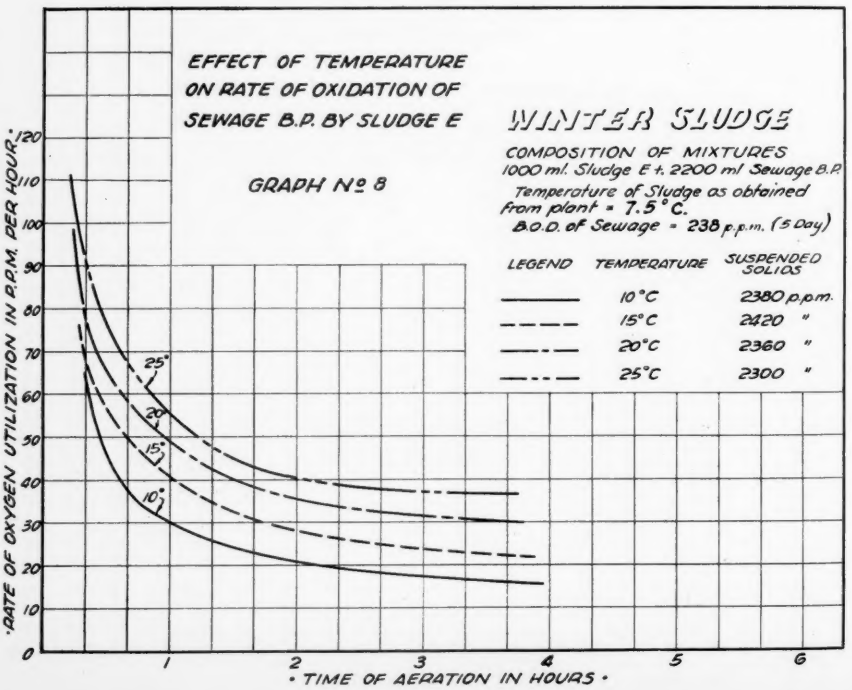

EFFECT OF TEMPERATURE
ON RATE OF OXIDATION OF
SEWAGE C BY SLUDGE C
GRAPH Nº 3
SUMMER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge + 2200 ml. Sewage
Temperature of Sludge as obtained from plant = 20°C
B.O.D. of Sewage = 445 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 3860 p.p.m.
15°C 4080 "
20°C 4040 "
25°C 4060 "
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°

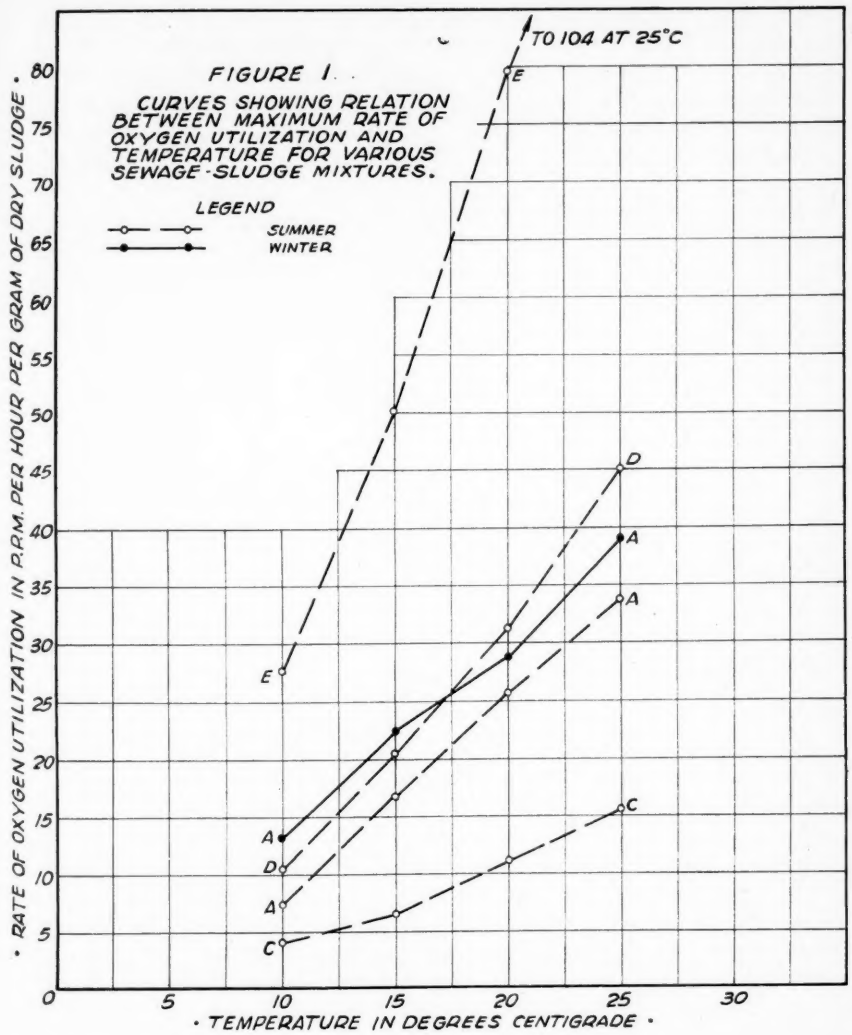

EFFECT OF TEMPERATURE
ON RATE OF OXIDATION OF
SEWAGE B.P. BY SLUDGE C.
GRAPH Nº 4
WINTER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge C + 2200 ml. Sewage B.P.
Temperature of sludge as obtained from plant = 11.1°C.
B.O.D. of Sewage = 140 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 3640 p.p.m.
15°C 3500 "
20°C 3560 "
25°C 3560 "
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°


EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE D BY SLUDGE D
GRAPH Nº 5
SUMMER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge + 2200 ml. Sewage
Temperature of Sludge as obtained from plant = 17°C.
B.O.D. of Sewage = 253 (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 1080 p.p.m.
15°C 1040 "
20°C 1060 "
25°C 1020 "
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°


EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE D BY SLUDGE D
GRAPH Nº 6
WINTER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge + 2200 ml. Sewage
Temperature of Sludge as obtained from plant = 9.5°C.
B.O.D. of Sewage = 530 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 1700 ppm
15°C 1600
20°C 1700
25°C 1560
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°


EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE E BY SLUDGE E
GRAPH NO. 7
SUMMER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. of Sludge + 2200 ml. Sewage
Temperature of sludge as obtained from plant = 16°C.
B.O.D. of sewage = 255 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 980 p.p.m.
15°C 960 "
20°C 980 "
25°C 1000 "
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°


EFFECT OF TEMPERATURE ON RATE OF OXIDATION OF SEWAGE B.P. BY SLUDGE E
GRAPH Nº 8
WINTER SLUDGE
COMPOSITION OF MIXTURES
1000 ml. Sludge E + 2200 ml Sewage B.P.
Temperature of Sludge as obtained from plant = 7.5°C.
B.O.D. of Sewage = 238 p.p.m. (5 Day)
LEGEND TEMPERATURE SUSPENDED SOLIDS
10°C 2380 p.p.m.
15°C 2420 "
20°C 2360 "
25°C 2300 "
RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR
TIME OF AERATION IN HOURS
25°
20°
15°
10°



24.0 per cent, respectively, of the rate found at 25° C. These results correlate quite closely with those reported by Sawyer and Nichols (1). Using identical sludges at the temperatures of 20, 15, and 10 deg. C., they obtained rate values of 70.5, 43.5, and 26.0 per cent respectively of that obtained at 25° C.

Inspection of Graphs 1 and 2 will show that the character of the oxidation curves produced by Sludge A under summer and winter conditions is essentially the same. This, however, is not the case with Sludge C, Graphs 3 and 4, or with Sludge D, Graphs 5 and 6. In these latter cases, the oxidation curves produced when using the winter sludge to oxidize sewage show no abrupt breaks. The sewage sub-

strates used for obtaining the data presented in each graph were collected from cities of such size and at such times that the authors feel confident the substrate in each case constituted a well balanced diet. The variation in the oxidation curves produced by Sludges C and D in summer and winter is probably due to seasonal variations in the biological make-up of the sludges. This is substantiated by nitrification data which will be discussed presently.

The curves given by Sludge E under both summer and winter conditions, Graphs 7 and 8, are essentially the same except for their behavior during the first few minutes. Since neither the summer nor winter sludge from this source showed any appreciable ability to oxidize nitrogen, this slight difference was attributed to variation in sludge condition or character of the sewage.

The amount of nitrification produced by the various activated sludge-sewage mixtures is shown in Table II. In the case of Sludge C

TABLE II.—*Nitrate Formation by Various Activated Sludge-Sewage Mixtures. Results in P.p.m.*

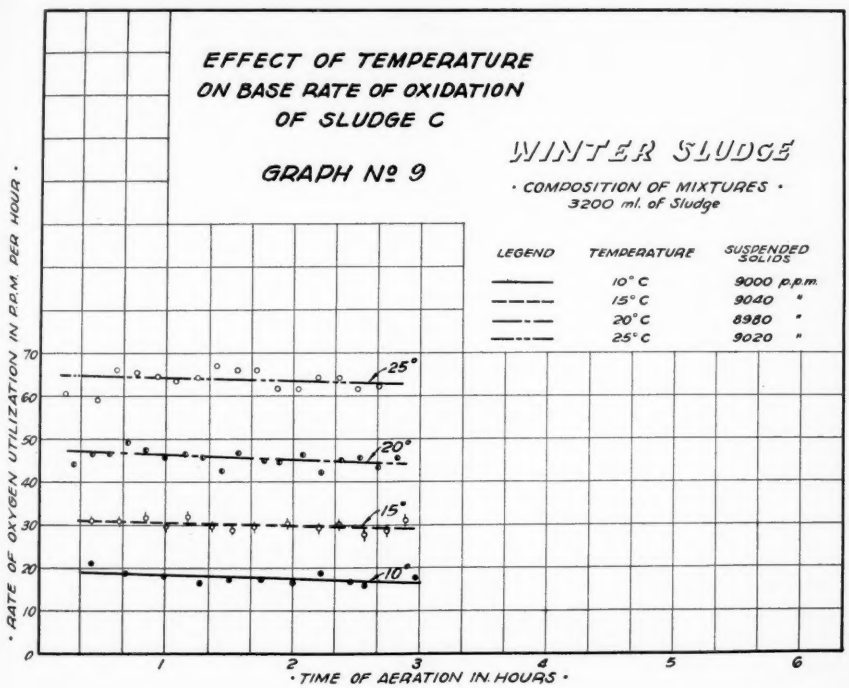
Source of Activated Sludge	Summer Sludge				Winter Sludge			
	25°	20°	15°	10°	25°	20°	15°	10°
A	24	24	24	14*	—	—	—	—
C	12	12	12	5*	None	None	None	None
D	15	15	12.5	5*	—	—	—	—
E	None	None	None	None	None	None	None	None

* Run discontinued before oxidation of nitrogen was completed, *i.e.* before abrupt break in oxygen utilization rate curve occurred.

obtained at the plant under winter conditions no nitrates were formed. This lack of ability to nitrify during winter explains the different types of oxidation curves produced by Sludge C. This effect of lack of nitrification may be grasped by comparing Graph 4 with Graph 3. Although no nitrification studies were made on winter Sludge D, the type of oxidation curve produced by it is typical of those given by non-nitrifying sludges and indicates that it, too, had lost the ability to nitrify in the transfer from summer to winter conditions. With Sludge E, the ability to form nitrates was not even attained under summer conditions. This is substantiated by both the nitrification data and the character of the oxygen utilization rate curves produced by the winter and summer sludges.

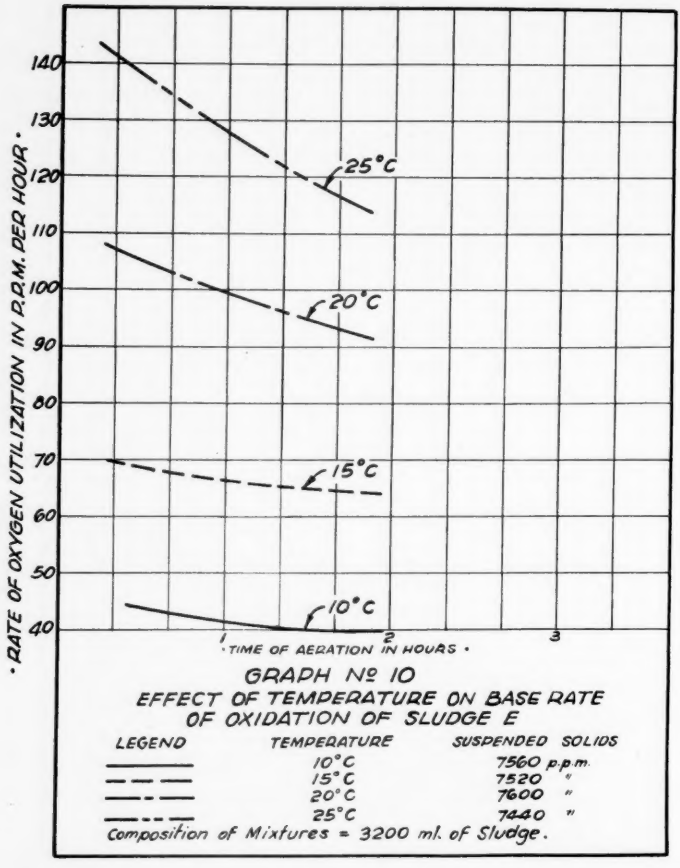
Table I shows that the effect of temperature on the rate of oxidation by Sludge E is about the same as for the other sludges. Since Sludge E differed from the others because of its inability to nitrify, it appears that the influence of temperature on the rate of carbonaceous oxidation must be of the same order as its influence on the rate of nitrification.

Base rates of oxygen utilization for each of the sludges studied were determined at the four temperatures previously mentioned (25, 20, 15, and 10 deg. C.). Each sludge, with the exception of Winter Sludge E, gave oxygen utilization rate curves at the different temperatures which were essentially horizontal, or showed only a slight gradual decrease as the aeration period progressed. Because of the similarity of the curves produced by Sludges A, C, and D, only one set of the curves obtained which show the influence of temperature on the base rates of oxygen usage (Graph 9) has been included in this paper. Due to the simplicity



and non-intervention of the curves in this case, the experimental points upon which the curves are based are included to illustrate the frequency at which data were taken and the variation of individual test points.

The base rates of oxygen usage obtained with Winter Sludge E, even after 24 hours of aeration prior to the start of the run, showed a decided downward trend as the aeration period progressed. These results are shown in Graph 10 and indicate that this particular sludge must have been considerably overfed. It is interesting to note in Graph 10 that the downward trend of each curve is a function of the temperature and is related to the rate of oxygen usage or the rate of stabilization. Base rate determinations on the same sludge at the different temperatures were made again after the sludge had been aerated for 72 hours at room temperatures without feeding. The results are

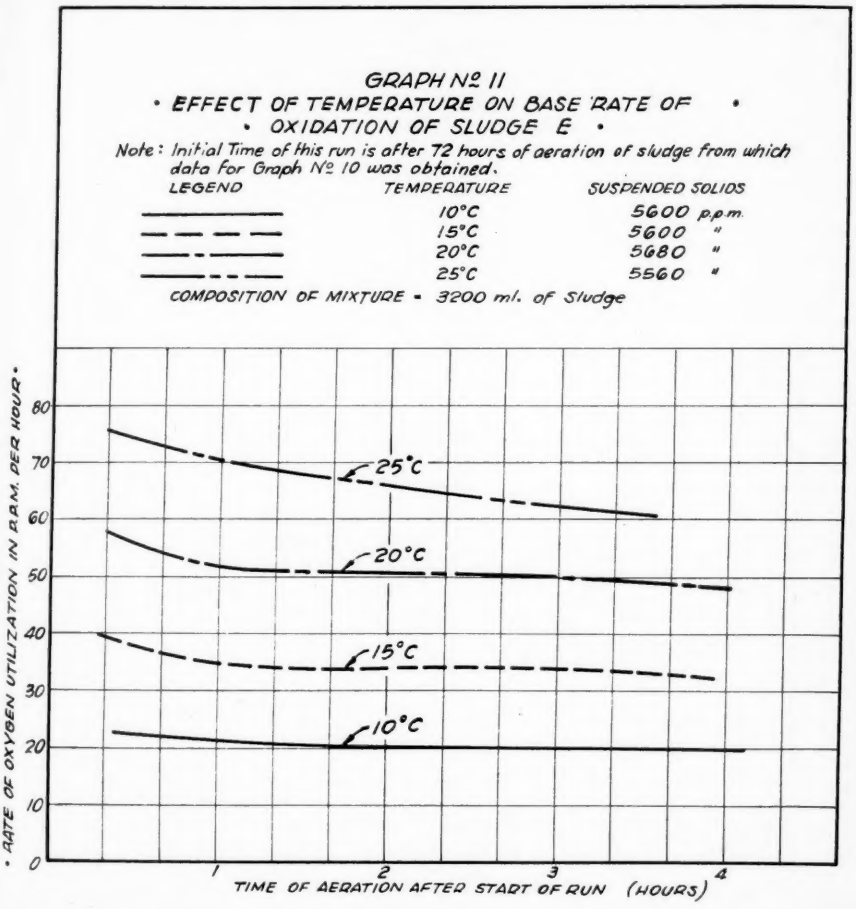


given in Graph 11 and indicate that the sludge had become quite well stabilized during the intervening time. During the 72-hour interval the volatile solids content of this sludge decreased from 74.7 per cent to 70.8 per cent. This behavior of the sludge in regard to its base rate of oxygen utilization correlates with that found for sludge from the same source as reported by Sawyer and Nichols (4).

Base rates of oxygen utilization per gram of suspended solids of the various sludges at the several temperatures studied have been evaluated and are given in Fig. 2. In general, the curves show relationships approaching a straight line between 15° and 25° C. There appears to be a change in the straight line relationship near 15° C. The similarity of the curves produced by the summer and winter sludges obtained from the same source is rather striking and indicates that even though the temperature coefficient of oxidation may vary slightly with different sludges, it remains about the same for sludge from the same source during both winter and summer.

It is of particular interest to note in Fig. 2 that in each case the

oxygen demand of the winter sludge exceeded that of the corresponding summer sludge. The demand for oxygen by the winter sludges from sources A, D, and E at 20° C. is nearly equal to the demand by the summer sludges at 25° C. In the case of Sludge C the demand of the winter sludge at 20° C. exceeds that of the summer sludge at 25° C. This is probably a manifestation of the compensating factor previously suggested to explain the usual uniform behavior of activated sludge



plants at the different seasons of the year. The data indicate that sludges are capable of overcoming a temperature differential of approximately 5° C. without any handicap. An explanation of this ability to compensate for temperature variations is found in Table III, which shows the variation of volatile solids content of the activated sludge with season. Again Sludge E appears to be an exception, but when consideration is given to variation in sludge characteristics, due to rainfall and other variables, exceptions are to be expected. The rapid

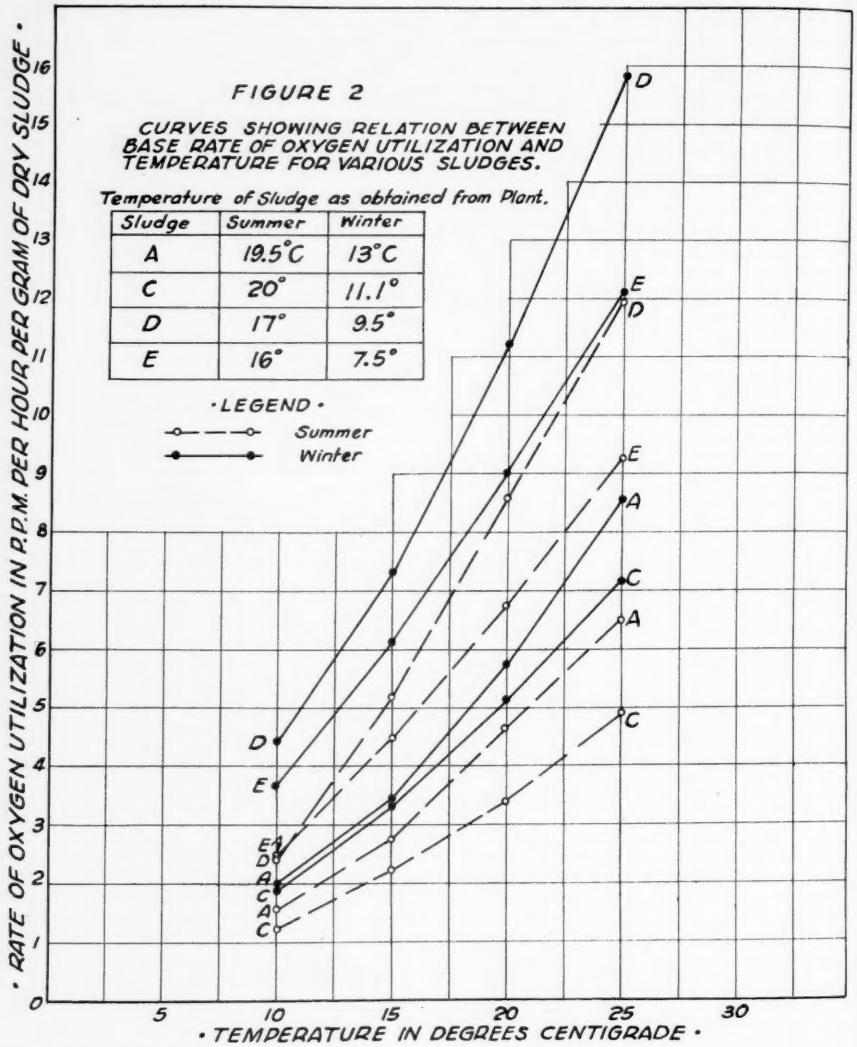


FIGURE 2
CURVES SHOWING RELATION BETWEEN BASE RATE OF OXYGEN UTILIZATION AND TEMPERATURE FOR VARIOUS SLUDGES.
Temperature of Sludge as obtained from Plant.
Sludge | Summer | Winter
A | 19.5°C | 13°C
C | 20° | 11.1°
D | 17° | 9.5°
E | 16° | 7.5°
·LEGEND·
Summer
Winter
· RATE OF OXYGEN UTILIZATION IN P.P.M. PER HOUR PER GRAM OF DRY SLUDGE ·
· TEMPERATURE IN DEGREES CENTIGRADE ·

increase in activity with small increase in volatile solids content per unit weight of sludge is well correlated with the findings of Grant, Hurwitz and Mohlman (5) and Sawyer and Nichols (4).

TABLE III.—*Volatile Solids Content of Various Sludges*

Source of Activated Sludge	Summer Sludge	Winter Sludge
A	75.7	79.6
C	71.4	72.4
D	80.3	84.4
E	76.6	70.8

A comparison of the relative influence of temperature on the base rate of oxidation of the various sludges is given in Table IV. Although

TABLE IV.—*Relative Rates of Oxygen Utilization by Various Activated Sludges Expressed in Per Cent. (Based on Value at 25° C. = 100%)*

Source of Activated Sludge	Temperature, Centigrade							
	25°		20°		15°		10°	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
A	100	100	71.6	67.1	41.9	40.0	24.0	23.5
C	100	100	69.0	71.9	45.3	46.4	25.2	26.4
D	100	100	71.8	70.9	43.3	46.2	20.2	27.8
E	100	100	72.8	74.2	48.3	50.2	26.6	30.1
Seasonal Avg.	100	100	71.3	71.0	44.7	45.7	24.0	26.9
Yearly Avg.	100		71.15		45.2		25.45	

there is some variation in the values between different sludges, there is in most cases very little difference between values obtained on summer and winter sludges from the same source. The constancy of the effect of temperature is probably best shown by the values found for the seasonal averages for all sludges.

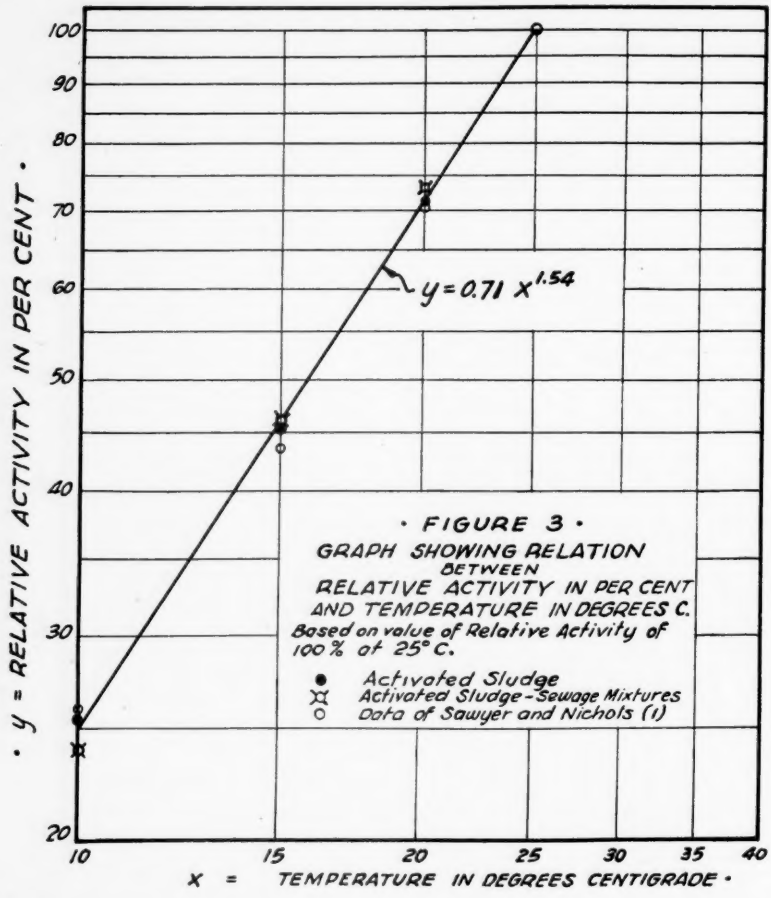
The data presented in Table V show that, in most cases, no nitrifica-

TABLE V.—*Nitrate Formation by Various Activated Sludges Alone. Values Expressed in P.p.m.*

Source of Activated Sludge	Summer Sludge				Winter Sludge			
	25°	20°	15°	10°	25°	20°	15°	10°
A	None	None	None	None	—	—	—	—
C	None	None	None	None	4	4	2	0
D	6	5	4	4	—	—	—	—
E	None	None	None	None	None	None	None	None

tion occurred when activated sludges alone were studied. The oxidation involved principally the stabilization of carbonaceous matter. The contention that the influence of temperature on the rates of nitrogenous and carbonaceous oxidation is essentially the same is further substantiated by comparison of the values shown in Tables I and IV. It will be seen that the yearly average values for relative rates of oxidation at the different temperatures in Table IV, involving little or no nitrification, correlate with the seasonal average values in Table I, involving considerable nitrification.

The average values of the relative rates of oxygen utilization of both the activated-sludge-sewage mixtures and of the activated sludges studied as given in Tables I and IV have been plotted logarithmically in Fig. 3. The values obtained by Sawyer and Nichols (1) in their study



of the influence of temperature on rate of oxygen utilization have also been plotted on the same curve. The results of this plotting yield a straight line on logarithmic paper. The equation for which may be easily written as $y = 0.71\,x^{1.54}$ where y is relative activity in per cent of that at 25° C. and x is temperature in degrees Centigrade. Although this formula is not proposed as final for interpreting temperature effects on oxygen utilization in activated sludges, it has been arrived at from data obtained on sludges from four different plants in three series of experiments constituting more than sixty separate test runs and covering a period of more than a year. Because of the small divergence in the results upon which this equation is based, it may find application in

plant control in providing a means of transferring laboratory data obtained at one temperature to conditions actually present in the plant at another temperature.

Discussion

According to the law of van't Hoff and Arrhenius, the rate of a chemical reaction is increased two or more times its original value whenever the temperature is increased 10° C. The investigations of early workers illustrated the lack of accuracy of the law through all ranges of temperatures and it soon took its rightful place as a "rule of thumb" guide when considering the effect of temperature upon chemical reaction rates.

Biologists have long been interested in the effect of temperature upon rates of biological processes and have in numerous instances found it to correlate quite well with the van't Hoff law over narrow temperature ranges. The temperature ranges of biological processes are naturally quite restricted and usually do not exceed 40° C. Within the favorable ranges of temperature, numerous investigations have shown that the temperature coefficient of reaction rate does not often remain constant, but instead, usually shows sharp breaks at transition temperatures. With psychrophilic organisms, a common transition temperature appears to be at or near 15° C. Glaser (6), in a study of the effect of temperature on the forward movement of *Paramecium,* found a uniform temperature coefficient over the range of 6–15° C. and a higher coefficient holding from 15–40° C. Orr (7) has reported on investigations of temperature on the oxygen consumption of the pupae of the *Drosophila melanogaster* and has shown temperature coefficients of different magnitude above and below 15° C. Stier (8) has investigated the rate of oxygen utilization by yeast as related to temperature and has found a uniform effect from 3–15° C., a second uniform effect from 15–30° C., and a third effect from 30–35° C. Wells (9) has reported on the influence of temperature upon the respiratory metabolism of the Pacific Killifish, *Fundulus parvipinnis,* and has found a marked change in temperature coefficients near 17° C. Crozier (10), an authority on the influence of temperature on biological oxidations, has suggested that 15° C. is probably the dividing line which separates the two rates of reaction.

It would be misleading to infer that there is unanimity of opinion as to the effect of temperature on rates of biological processes. Belehradek (11) has objected quite vehemently to the interpretation of the effect of temperature on rates of biological reaction based on temperature coefficients obtained for rates of chemical reactions.

Although the influence of temperature on the rate of many individual biological processes shows decided changes at certain temperatures, it would seem improbable that in a biological mixture as heterogeneous as activated sludge a well defined critical temperature would exist. The results shown in Fig. 2 indicate to some extent a change in the rate at 15° C., but it must be remembered in considering these data that they

are based on determinations made at 5° C. intervals and do not give the complete picture, since the experimental points as determined are connected by straight lines. If further simultaneous studies at smaller intervals of temperature show a decided change at 15° C., the contention of Crozier will have been verified.

The variation in the type of oxygen utilization rate curves produced by Sludges C and D under the extreme conditions of summer and winter is of considerable interest from a theoretical and also from a practical viewpoint. The authors feel certain that the difference in these cases was due to the ability of the sludge to oxidize nitrogen in summer and not in winter. On a theoretical basis it could be said that, at the low temperatures, conditions were so unfavorable for the growth and reproduction of the nitrifying organisms that they gradually died out. Certain other factors responsible for such differences have been investigated in this laboratory and will be reported in a later publication. From the operator's viewpoint, the character of the oxidation curve produced by his activated sludge is important in determining how he should apportion his air supply to attain best and most efficient results. This is of special importance in those plants of such size that control by "Tapered Aeration" is economically feasible.

The ability of activated sludge to compensate for the variations in temperature which it must undergo in temperate climates is becoming much better understood. Ruchhoft and Smith (12) have recently reported the results of a study in which they gradually increased the feeding load on a sludge in a small experimental continuous flow plant. They found that as the food load increased the volatile solids content of the sludge increased and the rate of oxygen usage by the sludge increased accordingly. Corresponding data have been obtained in this laboratory on sludges fed in a "fill-and-draw" manner. From this information the following theory may be advanced: For sludges fed identical amounts of food those at the lower temperatures will be overfed with respect to those at the higher temperatures, because of the lower rates of stabilization of food at the lower temperatures; as a result, there is an increase in volatile solids content and activity at the lower temperatures. This may well be the explanation of how the compensatory factor functions in activated sludge.

In the application of temperature-coefficient data to plant operation and, in particular, with respect to variation in quantity of aeration solids, it is our opinion that such changes to be beneficial must be approached with a long range program. Changes in the character of activated sludge, other than those caused by harmful substances, are slow and usually require three or four weeks time to reach equilibrium at the higher temperatures and a correspondingly longer time at the lower temperatures. An appreciation of this time lag is essential to intelligent application of temperature coefficient data.

Summary

1. The influence of temperature upon the rate of oxygen utilization by activated sludge and activated sludge-sewage mixtures obtained from four separate sources, under both summer and winter operating conditions, was found to be fairly uniform. For activated sludge alone, the average rates at 20, 15, and 10° C. were found to be 71.15, 45.2 and 25.5 per cent respectively of that found at 25° C. Activated sludge-sewage mixtures gave rates of similar magnitude, which averaged 73.4, 46.1 and 24.0 per cent of that found at 25° C.

2. The equation, $y = 0.71\,x^{1.54}$ in which y is the relative activity in per cent based on the value at 25° C. taken as 100 per cent and x is the temperature in degrees Centigrade, has been found to apply in general to the influence of temperature on the rate of activated sludge oxidations.

3. The influence of temperature on the rate of oxygen utilization by activated sludge was found to be the same regardless of whether or not nitrification occurred. Temperature has the same effect on rates of nitrogenous and carbonaceous oxidation.

4. The temperature coefficients of the activated sludge from any one of the four sources showed less variation between summer and winter operating conditions than the temperature coefficients for the four sludges at the same season.

5. The character of the oxygen utilization rate curves produced by two of the sludges when oxidizing sewage were found to vary with the seasons. This variation has been correlated with loss of ability to oxidize nitrogen during the winter months.

6. Winter sludges from all sources were found to use more oxygen at a given temperature than the corresponding summer sludges. This variation has been correlated with the compensating ability of activated sludge to overcome, in part, the influence of seasonal temperature changes.

Acknowledgments

The authors wish to express their appreciation to the Wisconsin Alumni Research Foundation for Grants-in-Aid which have made this research project possible, to Dr. W. D. Stovall, Director of the Wisconsin State Laboratory of Hygiene, for the loan of the Oxy-Utilometers, and to Prof. L. H. Kessler and Dr. M. Starr Nichols who have sponsored this project and have given freely of their counsel.

References

1. C. N. Sawyer and M. Starr Nichols, "Effect of Sludge Concentration and Temperature Upon Oxygen Utilization," *This Journal*, **11**, 51 (1939).
2. K. Viehl, "Uber den Einfluss der Temperature und der Jahreszeit auf die Biologische Abwasserreinigung," *Centralblatt für Bacteriologie*, **91**, 14 (1934).
3. C. N. Sawyer, "Factors Involved in Prolonging the Initial High Rate of Oxygen Utilization by Activated Sludge-Sewage Mixtures," *This Journal*, **11**, 595 (1939).

4. C. N. Sawyer and M. Starr Nichols, "A Comparison of Oxygen Utilization by Activated Sludges Obtained from Four Wisconsin Municipalities," *This Journal*, **11**, 462 (1939).
5. S. Grant, E. Hurwitz, and F. W. Mohlman, "The Oxygen Requirements of the Activated Sludge Process," *This Journal*, **2**, 228 (1930).
6. Otto Glaser, "Temperature and Forward Movement of *Paramecium*," *Jour. Gen. Physiol.*, **7**, 177 (1924).
7. Paul R. Orr, "Critical Thermal Increments for Oxygen Consumption of an Insect, *Drosophilia melanogaster*," *Jour. Gen. Physiol.*, **7**, 731 (1925).
8. T. J. B. Stier, "The Rate of Oxygen Utilization by Yeast as Related to Temperature," *Jour. Gen. Physiol.*, **16**, 815 (1933).
9. Nelson A. Wells, "The Influence of Temperature Upon the Respiratory Metabolism of the Pacific Killifish, *Fundulus parvipinnis*," *Physiol. Zoology*, **8**, 196 (1935).
10. W. J. Crozier, "On Biological Oxidations as Function of Temperature," *Jour. Gen. Physiol.*, **7**, 189 (1924).
11. J. Belehradek, "Temperature Coefficients in Biology," *Biol. Reviews*, **5–6**, 30 (1930–31).
12. C. C. Ruehhoft and R. S. Smith, "Changes in Characteristcs of Activated Sludge Induced by Variations in Applied Load," *This Journal*, **11**, 409 (1939).

STUDIES ON THE METHANE-PRODUCING BACTERIA *

IV. GROWTH OF METHANE-PRODUCING ORGANISMS IN SUPERNATANT SLUDGE LIQUORS

By H. Heukelekian and Bernard Heinemann

Associate and Graduate Student, Dept. Water and Sewage Research, New Brunswick, N. J.

In our attempts to find a suitable method for the examination of methane-producing bacteria, it was found that sterile ripe sludge was an excellent medium for the enumeration of these organisms. When small volumes of ripe sludge were incorporated in the synthetic medium there was a definite stimulation in the growth of the methane-producing organisms and a substantial reduction in the time of incubation. Neither of these expendients was considered suitable for a standard method of enumeration of these organisms because of the variability in the chemical composition of the sludge. However, it was expected that if ripe sludge contained the necessary food materials for the development of these organisms, fresh solids or septic solids would contain these ingredients to a greater extent, since it is recognized that degradation products of ageing fresh solids, such as volatile acids, increase. It was therefore considered of interest to compare the supernatant liquor from fresh solids, septicized for different periods, with supernatant liquor from ripe sludge as a substrate for the methane-producing organisms. It was hoped that as a result of these studies the cultivation and enrichment of these organisms, in a more readily procurable substrate than the synthetic medium, would be possible for large scale production of cultures. Furthermore, it was expected that the enumeration of the organisms grown in liquor from solids of different digestion periods would reveal whether there were growth promoting or growth inhibiting substances produced during the digestion period.

Methods

Samples of fresh solids and ripe sludge were obtained from a disposal plant receiving domestic sewage. Portions of these solids were allowed to settle and the supernatant liquor drawn off. Portions of fresh solids were allowed to become septic for different periods and the supernatant liquors drawn off. In another series a sample of fresh solids was limed daily during the septicization period until a pH of 7.2–7.6 was maintained without further additions of lime. This required a period of eight days, after which time the liquor was drawn off. The various supernatant liquors immediately upon removal from the solids were adjusted to pH 7.2–7.8 with lime, if not already within this range, and sterilized in flowing steam on three consecutive days for 45 minutes each day.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

To the sterilized supernatant liquors a sterile solution of 1 per cent Na_2S plus 5 per cent Na_2CO_3 was added (3 c.c. per 100 c.c. of liquor). The pH was adjusted to 7.0 with sterile HCl solution. The synthetic media containing acetate, butyrate and ethyl alcohol were prepared to be used as a basis of comparison with the various supernatant liquor substrates. The media and supernatant liquors were distributed to test tubes containing inverted vials and also to tubes for dilution purposes. The inoculum was taken from synthetic media containing actively growing cultures of acetate, butyrate and ethyl alcohol fermenting organisms. The media and the supernatant liquors were inoculated in duplicate with these cultures in serial dilution, sealed with valspar and incubated at 32° C. A tube was considered positive when there was evidence of gas production in the inverted vials. The numbers of the organisms were obtained by use of the tables for "most probable numbers of bacteria."

It was found necessary to add 1 per cent of ethyl alcohol as a nutrient to the supernatant liquor in which those particular organisms were grown, because ethyl alcohol was present only in very small quantities in the original liquors or was lost as a result of heat sterilization. The acetate and butyrate fermenting organisms, on the other hand, were grown in the liquors as obtained without any further addition of nutrients.

Results

In Table I are given the numbers of acetate, butyrate and ethyl alcohol fermenting organisms growing in the supernatant liquors from

Table I.—*Counts of Methane-Producing Bacteria Using Various Supernatant Liquors in Growth Medium*

Substrate	Number of Organisms per C.c. (× 1000)		
	Acetate Fermenters	Butyrate Fermenters	Ethyl Alcohol Fermenters
Fresh Solids	6,000	2,000	2,500,000
Septic Solids*	130	2.5	0.25
Ripe Sludge	5,000	2,500	3,000,000
Culture Media	2,500	1,300	1,300,000

* Septicized for 14 days under acid conditions.

fresh solids, septic solids (14 days septicization period), digested solids and the culture media. The lowest counts were obtained in supernatant liquors from septic solids and the highest in fresh solids and ripe sludge liquors. Somewhat lower counts were obtained in synthetic media than in the liquors from ripe sludge or fresh solids. It was observed that the amount of gas formed was small in the liquor from ripe sludge by the acetate and butyrate fermenting organisms, due probably to the scarcity of nutrients.

In the next experiment the effect of the period of septicization of fresh solids on the growth of the organisms in the supernatant liquors was studied after periods of aging of 2, 5, 8, and 12 days. In addition, the effect of liming the solids during the septicization period was also studied. Finally, the effect of adding an equal volume of ripe sludge liquor to liquor of fresh solids septicized for a period of 12 days was determined. The various liquors after sterilization were inoculated with acetate fermenting organisms. The numbers of organisms developing on these substrates are given in Table II.

TABLE II.—*The Effect of Septicization, of Liming During This Period, and Addition of Ripe Sludge Liquors to Septic Liquor, on the Counts of Acetate Fermenting Organisms*

Supernatant Liquors	Number of Organisms per C.c. (× 1000)
Fresh Solids	250
2 day Septic Solids	6
5 " " "	2
8 " " "	25
12 " " "	2.5
8 Day Limed Solids	250
12 Day Septic Solids Plus Ripe Sludge Liquor	250

The results show that the highest counts of acetate-fermenting, methane-producing organisms were obtained in supernatant liquors from fresh solids, solids limed during the septicization period and 12-day old septic solids liquor to which an equal volume of ripe sludge liquor had been added after the septicization period. Septicizing the solids for a period of two days lowered the counts obtained from 2,500,000 to 6,000 per c.c. Septicization up to a period of twelve days did not give an increase in the count.

Analyses were made of the gas produced when enriched cultures of methane producing organisms were inoculated into supernatant liquor from fresh untreated solids The results were as follows:

	CO_2	CH_4
	%	%
Acetate fermenters	36	64
Butyrate fermenters	31	69
Ethyl alcohol fermenters *	15	85

* Supernatant liquor reinforced with 1 per cent ethyl alcohol.

The validity of using gas production in the vials as a criterion of the presence of methane organisms, when using the supernatant liquors as substrate, is thus substantiated.

DISCUSSION

The results presented show that liquor from septic solids is not as good a medium for the development of methane-producing organisms as liquor from ripe sludge or fresh solids. This deleterious effect is

not due to the low pH values of the septic solids since the pH values were adjusted prior to the use of the liquor as a culture medium. From the standpoint of the amount of food materials available for the methane-producing organisms the septic solids should be the most favorable. These facts suggest the production of certain growth inhibiting substances during the acid digestion period. The length of time these substances remain in the liquor during the digestion period is unknown, but there is little doubt that by the time the digestion is completed their influence has disappeared. That there is no danger of inhibition of methane fermentation by such substances when solids are digested with ripe sludge is indicated by the neutralizing effect of inhibiting action of septic solids by ripe sludge liquor. In the digestion of fresh solids without ripe sludge the delay in the onset of gas and methane production has been ascribed to the low pH value and the low numbers of methane producing organisms in fresh solids. A third factor can now be added, namely the inhibition caused by the production of growth inhibiting substances during the acid digestion period.

It was previously shown (2) that by adding lime and enriched cultures of methane-producing organisms the time necessary for the digestion of fresh solids without ripe sludge was considerably reduced. It was further shown that when the fresh solids were limed after a period of septic action and inoculated with enriched cultures of methane-producing organisms the stimulation in the digestion was not so marked as when the cultures were added to the solids which were prevented from becoming acid by the addition of lime. In view of the results presented in this paper it can readily be seen that the failure of the cultures to stimulate the digestion of solids subjected to prior acid digestion, even though subsequently limed, was due to the production of growth inhibiting substances during this period. That the action of lime is one of preventing the production of these substances, rather than neutralizing their effect after they are produced, is indicated by the fact that there is no inhibition if the lime is added during the septicization period but if lime is added after the solids are digested under acid conditions, there is little or no removal of the inhibiting substances. Here is an indication that products are formed when solids are digested under acid conditions which are not formed when solids are digested with lime and therefore the course and nature of these two types of digestion are entirely different and cannot be directly compared.

As to the nature of these inhibitory substances there is not much information. The work of Rudolfs and Chamberlin (4) showed a marked inhibition by indole and skatole on digestion. Rudolfs and Ingols (5) have reported the presence in septic solids of amounts of indole and skatole sufficient to affect the activities of the organisms present. It would be interesting to show whether substances are produced during the septicization of solids which inhibit the growth of other types of organisms important in the digestion of solids besides the methane-producing organisms.

The prevention of the inhibitory action of the septic solids liquor

by the addition of ripe sludge liquor may be explained in either of the following ways: (1) certain substances in ripe sludge neutralize the inhibitory substances of the septic liquor by detoxifying action; (2) growth promoting substances in ripe sludge liquor overcome and counterbalance the growth inhibitory action of the septic liquor. That such growth promoting action may be present in the liquor from ripe sludge and fresh solids is indicated by the higher counts obtained in these substrates over the counts obtained in synthetic media.

Thus it has been shown that fresh solids or ripe sludge liquor will serve as ideal substrates for culturing the methane-producing organisms for the digestion of fresh solids by artificial inoculation with enriched cultures. By providing an inert carrier for the organisms and replenishing the supernatant liquors, as the food supply in them becomes exhausted, an enriched culture can be obtained, as was done with synthetic medium.

Fair and Klein (1) reported that septicization of fresh solids for different periods prior to seeding did not result in progressive retardation of digestion but somewhat erratic and unpredictable variations were obtained. Heukelekian (3) found that the ageing of sewage solids up to two weeks did not cause an appreciable retardation of digestion upon seeding. In view of the results reported in this paper these apparently conflicting results may be understood on the basis of the relative rates of production and destruction of these growth inhibitory substances in ageing fresh solids and the relative importance of the growth promoting substances in ripe sludge. It would furthermore appear that the practice of withdrawing supernatant liquor from digestion tanks would have little effect on the rate of methane production because there is little inhibiting action in the presence of ripe sludge. The only effect of too rapid drawing off of liquor might be a slight reduction in the yield of gas.

Summary and Conclusions

Supernatant liquors from fresh solids at different periods of septicization, with and without liming, and liquor from ripe sludge, were used as the only substrates for growth of methane-producing bacteria. It was found that fresh solids and ripe sludge liquors, when used as culture media, allowed the development of maximum numbers of methane-producing bacteria and that septicization for even a two-day period limited the growth of these organisms. Liming during the ageing period of fresh solids, and the use of the supernatant liquor as substrate, allowed the development of as many organisms as the fresh solids or ripe sludge liquors. The addition of ripe sludge liquor to septicized solids liquor, prior to its use as culture medium, permitted the growth of as many organisms as the fresh solids liquor. The counts obtained from the synthetic culture media were lower than the counts obtained from fresh solids or ripe sludge liquors.

It is concluded that septicization of fresh solids results in the bacterial production of growth inhibitory substances inimical to methane

organisms. It is further concluded that there are certain growth promoting substances in ripe sludge which overcome this action of the inhibitory substance in the septic liquors.

REFERENCES

1. G. M. Fair and L. Klein, "The Effect of Age of Sewage Solids Upon Their Digestibility," *This Journal*, **1**, 14 (1928).
2. H. Heukelekian and Bernard Heinemann, "Studies on the Methane-Producing Bacteria. III. Digestion of Sewage Solids by the Addition of Enriched Cultures of Methane-producing Organisms," *This Journal*, **9**, 571 (1939).
3. H. Heukelekian, "Effect of Age of Fresh Solids on Digestion," *This Journal*, **1**, 309 (1929).
4. W. Rudolfs and N. S. Chamberlin, "Effect of Indole and Skatole on Digestion," *N. J. Agr. Exp. Stat., Bull.*, **529**, p. 41 (1932).
5. W. Rudolfs and R. S. Ingols, "Growth-Promoting Substances in Sewage and Sludge. II. Indole and Skatole," *This Journal*, **10**, 653 (1938).

Plant Operation

SLUDGE DISPOSAL AT THE MINNEAPOLIS–SAINT PAUL PLANT

By George J. Schroepfer *

Chief Engineer and Superintendent, Minneapolis-Saint Paul Sanitary District

The following paper describes the operation of the sludge disposal facilities at the Minneapolis-Saint Paul plant in the year from September 1, 1938, to August 31, 1939, and discusses some of the operating problems which presented themselves and the methods employed in overcoming them.

To permit a proper consideration of the sludge disposal process utilized in any particular plant, it is necessary to consider the treatment process which produces the sludge. The treatment process at this plant consists essentially of screenings and grit removal, and sedimentation, augmented at varying low river flows by effluent filtration in filters of the magnetite sand type, and chemical treatment. Provision has been made for disinfecting the effluent with chlorine during the summer season. While effluent filtration, chemical treatment and chlorination were practiced for various lengths of time during the period covered by this paper, the sludge disposed of was produced in the main by sedimentation only.

In evaluating the data presented herein and in analyzing the statements made, consideration should be given to the fact that the treatment plant was placed into operation on June 1, 1938, and the first sludge disposed of by vacuum filtration on July 2, 1938, and incineration begun on July 21, 1938. For various reasons associated with starting a plant of this type, operation during the first several months is not representative of regular operation. It was not until the early part of December 1938, that continuous routine operation was effected, after which all sludge produced by the plant was filtered and incinerated.

Description of Sludge Disposal Facilities.—All equipment required in the sludge disposal process is housed in the Filtration and Incineration Building, which has an area of 17,325 sq. ft. and varies from a single to six stories in height. Briefly described, the sludge disposal process functions in the following manner. Sludge is pumped from the settling tanks to either of two concentration tanks. After a period of one to two days the thickened sludge flows to either of two bucket elevators which raise the sludge to the conditioning tanks, from which it is carried by gravity to any one of various combinations of six vac-

* Presented at the Twelfth Annual Convention of the Central States Sewage Works Association, Chicago, Ill., October 12, 1939.

uum filters. The filter cake is conveyed by belt conveyors to any one or combination of the three incinerators. The ash produced is sluiced to pumps by means of which it is conveyed to the dump.

The equipment required in the disposal of sludge is as follows:

(*A*) *Vacuum Filters and Appurtenances*

(1) Chemical unloading and storing. Pneumatic conveyor 6 tons per hour capacity discharging into four bins of combined capacity of 2700 cu. ft.

(2) Chemical feeding. Two dry chemical feeders with lime slakers, range 200 to 1200 lbs. per hour. Two dry chemical feeders, range 100 to 600 lbs. per hour. Two solution feeders, range 12 to 120 gals. per hour.

(3) Vacuum filters. Six units 11 ft. 6 in. diameter by 14 ft. long (500 sq. ft.).

(4) Vacuum pumps, blowers and filtrate pumps. Three vacuum pumps, capacity 1850 cu. ft. per min. each, three blowers 800 cu. ft. per min. each, and three filtrate pumps 250 gals. per min.

(5) Two continuous conveyor belt sludge weighing scales, capacity range each 2 to 30 tons per hour.

(*B*) *Incinerators and Appurtenances*

(1) Three multiple hearth type incinerators 22 ft. 3 in. outside diameter, 8 hearths, 60 tons dry solids daily nominal capacity each.

(2) Fans and preheaters. One plate type preheater for each incinerator. Total of three hot air fans each of 11,000 cu. ft. per min. capacity, and three hot gas fans, capacity 36,000 cu. ft. per min. each.

(3) Ash sluicing and pumping equipment. Capacity 720 tons dry ash per 24 hours.

(*C*) *Concentration Tanks*

Two tanks each 18 ft. wide, 25 ft. deep and 95 ft. long, each having a capacity of 41,000 cu. ft. equipped with collector mechanisms.

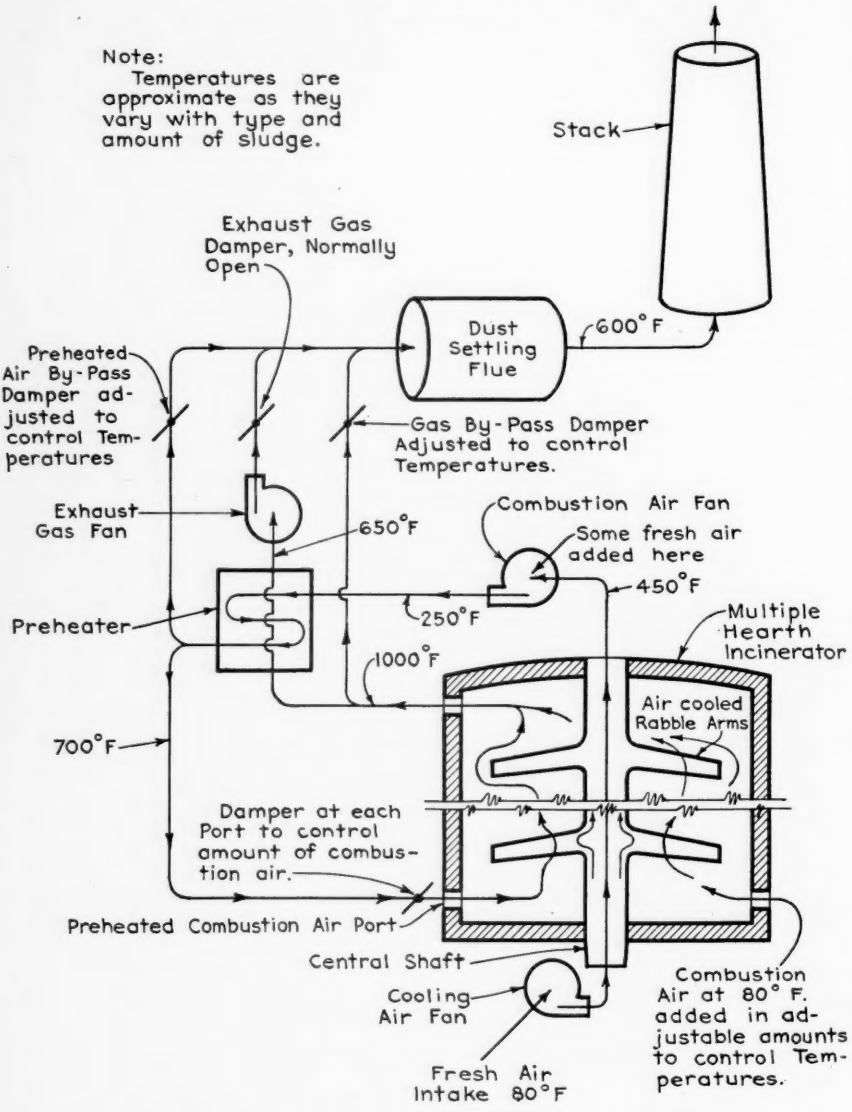
Character of Sludge.—The raw sludge delivered to the concentration tanks varies over quite a wide range in quantity and in the characteristics that affect filtration and incineration. Referring to Table I, the raw sludge as removed from the settling tanks in the period from September 1, 1938, to August 31, 1939, averaged as follows: pH 6.0 moisture content 92.16 per cent, and volatile solids 63.4 per cent After concentration for a period which generally varies from one to two days, the pH of the sludge had changed to 5.9, the moisture content to 90.64 per cent, and the volatile solids to 62.2 per cent.

Sludge Conditioning.—From the concentration tanks the sludge is delivered to bucket elevators by means of which it is elevated and discharged into the sludge conditioning tanks. The elevators are provided with variable speed drives, the speed of which controls the quantity of chemicals which are fed. The conditioning tanks are provided with means for varying the detention period by changing the depth of sludge in the tanks. The time of sludge conditioning has averaged 24 minutes in the period covered by this paper.

TABLE I.—*Summary of Data on Sludge Characteristics and Vacuum Filtration*
Year Ending August, 1939

Month	pH		Total Solids—Per Ct.			Volatile Solids—Per Ct.			Average Tons of Material Daily			Conditioning Chemicals, Per Ct. of Sewage Solids		Av. Rate Lb. per Sq. Ft. per Hour
	Raw Sludge	Thickened Sludge	Raw Sludge	Thickened Sludge	Filter Cake	Raw Sludge	Thickened Sludge	Filter Cake	Dry Sewage Solids Filtered	Wet Cake Produced	Incinerator Ash Produced	CaO	$FeCl_3$	
Sept. 1938	6.4	5.9	7.80	9.10	34.5	59.3	59.5	51.4	44.5	136.7	23.0	10.30	3.30	7.31
Oct.	6.3	6.3	6.29	8.20	34.3	65.0	64.2	52.6	60.8	194.0	31.5	11.70	2.69	5.68
Nov.	5.9	6.1	7.40	9.16	35.1	63.5	62.7	52.6	75.0	216.0	36.0	10.70	2.58	5.02
Dec. 1938	5.8	5.8	7.10	8.65	34.2	67.9	66.2	54.7	97.6	317.0	49.0	11.20	2.80	5.05
Jan. 1939	6.2	5.9	7.70	9.52	36.1	64.6	63.9	55.9	101.6	326.6	52.1	8.78	2.36	6.21
Feb.	6.1	6.0	7.18	8.87	34.8	67.8	66.8	62.3	104.0	309.4	41.0	5.76	2.34	4.47
Mar.	6.1	6.0	10.25	11.18	39.1	56.6	55.7	54.3	121.1	285.5	50.0	3.24	1.76	4.90
Apr.	6.0	5.9	8.04	9.61	35.0	65.2	63.2	59.1	102.2	313.3	46.7	4.80	2.06	4.84
May	5.8	5.7	9.08	10.06	35.3	64.8	64.1	60.1	107.7	320.4	48.7	4.72	2.02	5.29
June	5.8	5.7	8.53	10.74	38.3	59.2	56.5	53.9	124.2	317.6	57.2	4.61	2.07	5.29
July	5.7	5.6	7.58	9.05	35.3	62.9	60.8	56.6	90.9	273.5	42.6	5.83	2.44	4.97
Aug. 1939	5.7	5.6	7.22	8.42	33.9	64.7	63.1	58.2	83.7	269.3	39.0	5.97	2.14	4.71
Average	6.0	5.9	7.84	9.36	35.4	63.4	62.2	56.0	92.6	273.0	43.0	7.30	2.38	5.31

The chemicals used for conditioning, except for short periods when ferric chloride alone was used as an experiment, have been lime and ferric chloride. During the entire year the quantity of ferric chloride



Air and gas flow diagram.

has averaged 2.38 per cent. of the weight of dry sewage solids, and the lime 7.30 per cent. However, during the last six months of this period the quantity of chemicals averaged considerably less, or 2.08 per cent ferric chloride and 4.88 per cent lime.

Control of the quantity of chemicals used for sludge conditioning has been a physical examination of the cake and the sludge by the operators checked by relatively frequent laboratory tests. Plans are now being made for the continuous control of filtration by the filter operators themselves by means of Bueckner funnels. While provision has been made in the way of equipment for the use of other chemicals at present prices (ferric chloride somewhat less than $44.00 per ton and lime somewhat less than $7.75) the continued use of these chemicals is indicated at least for the time being.

Proper mixing and agitation of conditioned sludge prior to filtration is of utmost importance, especially with heavy sludge. The use of large quantities of low pressure air administered at a number of points resulted in improvement in filtration and a consequent reduction in chemicals required. As originally installed, high pressure air was supplied through porous tubes. Upon failure of this arrangement to perform in a completely satisfactory manner, various methods were employed, culminating in one in which a total of eighteen small pipes was added to each tank and excess low pressure air from the blowers provided for removing cake from the filters was utilized for agitation. Means for distributing the chemicals more uniformly through the tank were provided. Studies are under way to effect additional improvements in sludge conditioning.

It has been found that the quantity of chemicals required for sludge conditioning is less with heavy sludge, which condition is usually associated with rains carrying inert material into the sewage. The sludge has been as heavy as 23 per cent solids. With the particular design of sludge piping installed in this plant sludge containing over 10 to 12 per cent. solids usually requires thinning with plant effluent to permit its movement through the piping system.

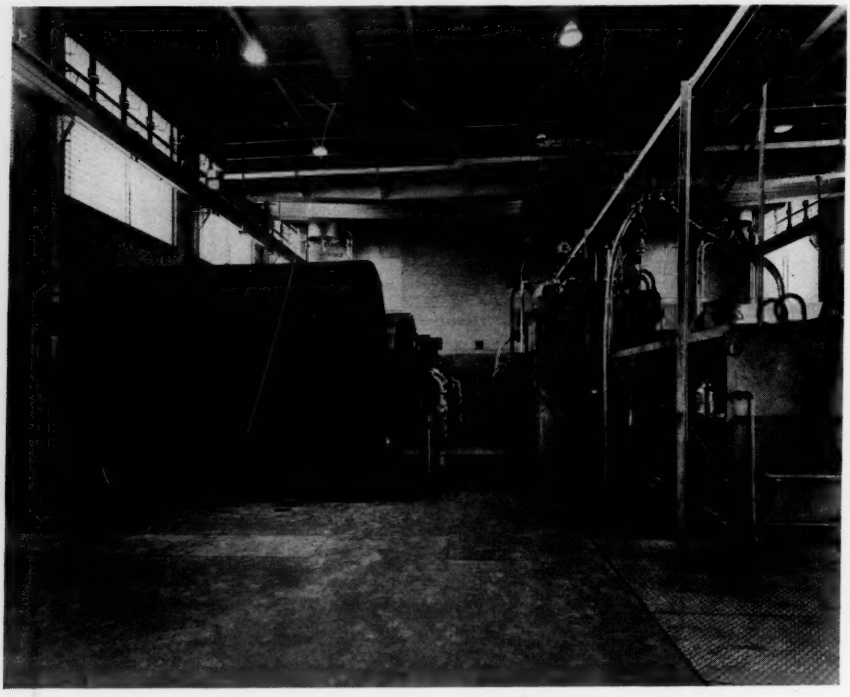
To observe the effect of longer storage on the amount of chemicals required for sludge conditioning, sludge has been held as long as seven days. No material increase in chemicals was required and no appreciable drop in filter rate was experienced. However, an increase in the odors produced by the sludge is noticeable with long-time storage.

Vacuum Filtration.—As in sludge conditioning, a number of improvement changes were made in this portion of the plant which have resulted in simplified operation and marked reductions in operating cost. As an example of the effect of these changes, during early operation approximately 3 per cent ferric chloride and 10 per cent lime were required, which has been reduced by various means to 2 and 5 per cent respectively. On the basis of 100 tons of dry sewage solids daily this amounted to a saving, on the basis of chemical prices current at the time, of $100 per day in chemical costs.

The sludge cake produced during the year averaged 35.4 per cent solids (64.6 per cent moisture). As a monthly average during March the moisture content was as low as 60.9 per cent. Daily averages have been as low as 50 per cent, these low moisture contents being associated with rains and periods when the volatile solids were exceptionally low.

The volatile solids in the filter cake vary widely. During the year ending August, 1939, the volatile solids in the filter cake averaged 56.0 per cent. with a range in monthly averages from 51.4 to 62.3 per cent. Daily variations are still greater. During the same period, the maximum per cent volatile solids for any one day was 69.3 per cent and the minimum was 33.5 per cent.

A total of 105,315 tons of filter cake have been produced by the plant since operation started on July 2, 1938. For the past year the quantity of dry sewage solids has averaged 92.6 tons daily, equivalent to 273 tons of filter cake daily. During the last nine months, from December



Vacuum filters and sludge conditioning.

1, 1938, when all sludge was filtered and incinerated, the quantity of dry solids has averaged 103.7 tons daily, equivalent to 303.6 tons of filter cake.

The reduction in the use of lime already mentioned resulted in other operating advantages. In early operation difficulty was experienced with lime blinding of the cloths, and after a period of several months operation the openings on the screen supporting the cloth had been reduced to less than one-quarter of their original area by calcium carbonate deposits. A number of methods of removing this material were tried. At one time it appeared desirable to purchase new screens at a cost of $193 per filter. Finally the screens were removed and sand-

blasted at a cost of only $15 per filter, with entirely satisfactory results.

In connection with methods employed to remove calcium carbonate from the screens, conditioning with ferric chloride alone was practiced. It was determined, after a short time of operation on two of the filters, that this method, while effective, was not economical. The experiment, however, permitted a determination of the effectiveness of this chemical alone for conditioning. The rate of filtration as compared with lime and ferric chloride was reduced, ranging from 3 to 4 lb. per sq. ft. per hour for dosages of 3 to 4 per cent of ferric chloride.

For the entire period of one year the average filter rate was 5.31 lbs. per sq. ft. per hour. During the early period when higher chemical dosages were used, the rates were considerably higher, averaging as much as 10 lbs. over relatively long periods of time. In addition to the higher operating costs to secure greater rates, the production of a thick cake presented certain operating problems in the conveying of the cake which were undesirable. In view of the fact that the increased power cost by using more filters was insignificant and the extra cost of cloths was small in comparison with the savings in chemicals which could be effected, the desirability of operating with lower filter yields was apparent. In emergencies, or under extreme peak conditions, it may be necessary to use higher chemical dosages to increase the filter rate.

The problem of increasing filter cloth life has been given due consideration. In the early period of operation cloths generally had to be removed after about 150 hours of usage. The necessity of removal was dictated by the fact that lime blinding necessitated higher chemical dosages and more frequent washing, and ripping or rotting at seams required the use of a large number of tin patches (as many as 30 to 40 on a filter) even with this short life. With reduced lime dosage the economical cloth life has been increased to somewhat over 200 hours, the use beyond which requires increased chemical feed incommensurate with the cost of cloth replacement, especially in view of reduction in cost of cloth which has been effected. The ability to purchase identical cloths locally at a fraction of their original cost has made it possible to change filter cloths more frequently than was formerly the case. In addition, the new cloths are sewed with a different type of thread and with a lock stitch with the result that difficulties at the seams requiring patching have been eliminated.

The filtration of raw sludge results in the production of some odors in the filter room not usually present in the case of digested sludge. However, the odor problem has not been sufficiently serious to justify the expenditure of funds for its correction.

Changes have been made in the location and angle of incidence of water sprays used in washing filters as compared with the type ordinarily manufactured. Various types of sprays arranged at different angles relative to the drum surface were tried with the result that the original sprays were reversed, and located so that water would impinge almost at right angles to the cloth on the drum. The new ar-

rangement permitted better washing in one-third of the time previously required, with the use of less water and the elimination of the necessity of brushing the cloth with resultant longer cloth life.

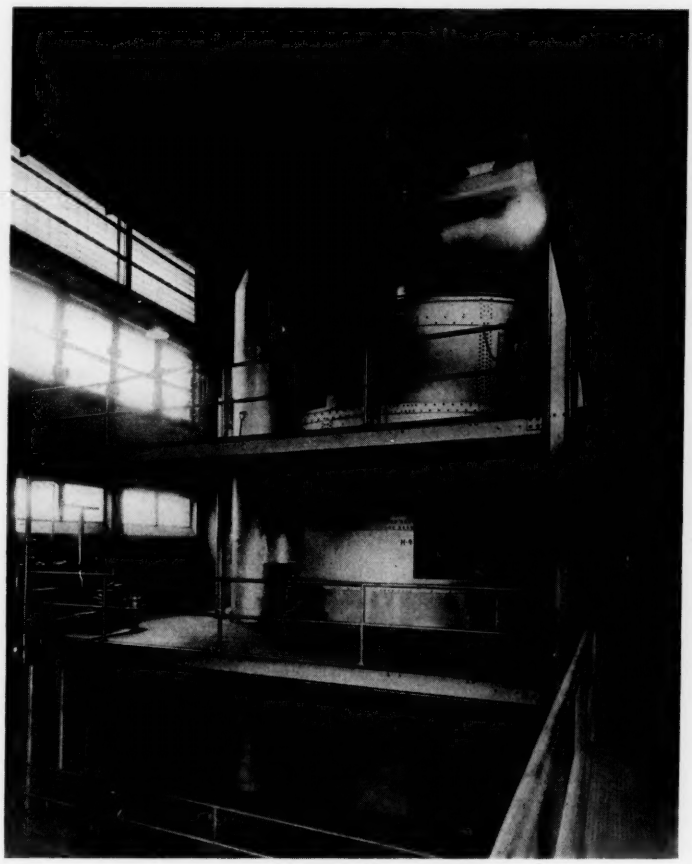
The problem of conveying filter cake on belts presents many difficulties which are sometimes not recognized. Plug-ups are quite frequent with relatively minor restrictions in openings around and over belts and at transfer points. These problems are aggravated with thick cake (heavier than ⅜ inch). It was found early that large blocks of cake as long as 8 ft. and as wide as the filter drum were broken off as the drum revolved. Various methods of breaking up this cake were considered, resulting in the selection of the simple and effective expedient of installing sloping ¼-in. rods on 12-in. centers in the filter take-off plates which cut the cake into 1 ft. wide ribbons which break off irregularly and have eliminated difficulties from this cause.

An unusual problem which presented itself was the curling of conveying belts carrying sludge cake. Two of seven belts used for this service began to curl downward at the edges after several months of service, in spite of the fact that the carrying idlers for over half of the length of the belt are troughed in the opposite direction. Engineers of three leading belt manufacturers, after analysis of samples of the belt, decided that the cause was grease contained in the sludge which had penetrated the belt cover, indicating the necessity of using oil resistant rubber on the belts. After about ten months of service the curling stopped, and for some reason the belts began to flatten out. The explanation for some of these happenings has not been found, and because of certain special conditions of use, this matter may not be of general interest. It is, nevertheless, one which arises in connection with mechanical sludge disposal methods.

Incinerators.—Incineration of sludge was begun on July 21, 1938, and 24-hour operation on July 29. On August 4, 1938, the first incinerator placed in operation heated up to the point at which the manufacturers' representatives considered it was necessary to shut down in order to insulate the rabble arms on certain of the hearths. Incinerator temperatures up to 2200 degrees F. were recorded as compared with expected maximum temperatures of 1600 degrees F. The high temperatures required the replacement of several of the rabble arms and a section of the central shaft on this incinerator.

The explanation for this condition is simple. Instead of requiring approximately $2,500 of fuel oil a month, as estimated, it was found early that under practically all conditions of operation an excess of heat existed, and no fuel was required for actual incineration. It was the manufacturers' expectation that the location of burning and the temperatures of combustion would be controlled by the use of varying quantities of oil introduced at different points. Instead it was necessary to dissipate heat to the extent of more than 6,000,000 B.T.U. per hour per incinerator. In the beginning the manufacturers attempted to accomplish this by introducing water into the furnace through sprays. While this was effective, it was considered unsatisfactory by

the District to use the large quantity of water required, and after experimenting with different methods for solving their difficulties, the manufacturers installed a bypass to conduct preheated air direct to the stack. In this way air at room temperature could be used for combustion and the quantity of water reduced to reasonable quantities and its addition required on less frequent occasions.



Incinerator.

Continuous operation of all the incinerators was possible beginning November 17, 1938, and in accordance with the specifications the acceptance tests were begun thirty days later, on December 17, and satisfactorily completed March 17, 1939. During that period all filter cake produced was incinerated, and one or more incinerators were in operation each day of the tests.

During the test period hourly records were kept of the quantity of sludge incinerated, fuel oil and power consumed, labor required, draft

conditions at four different points, temperatures at ten different points, the percentage CO_2 in the discharge gases, and frequent observations of smoke and odor conditions were made. Samples of filter cake, composited from individual samples collected at 2-hour intervals, were analyzed daily for total moisture, total solids, combustible solids and ash content. All analytical work was performed in accordance with the terms of the contract.

The summary of quantities and properties of filter cake incinerated, and the factors making up the item of operating costs are shown in Table II. During the ninety-day period a total of 28,242.8 tons of filter cake, equivalent to 10,017.0 tons of dry solids, were incinerated.

In Table III are shown the actual costs of operation and maintenance during the 90-day test period compared with the guaranteed costs. These costs are on the basis of unit costs specified by the District for comparison of proposals. Supplies and repairs during the 90-day test were assumed to be the total cost per day for these items set forth in the contractor's guarantee. The actual costs during the test period were well below the guaranteed figures. The costs shown in Table III are not comparable to those shown later in Table V. Those shown in Table III cover only such equipment and cost items included in the incinerator contractor's guarantee of costs.

The method of correcting some of the early difficulties with overheating, etc., was a matter of thorough investigation over a period of five months, and presented some rather interesting problems. A number of solutions were progressively considered and the methods finally adopted were those selected after careful consideration of all factors by the Sanitary District and the Contractor. Some of the difficulties appeared insuperable at times, but it is a pleasure to report that they were successfully overcome by the Contractor.

The following is extracted from the conclusions of the final report prepared upon completion of the incinerator acceptance tests:

> . . . (2) The incinerators are capable of incinerating the tonnage for which they were guaranteed, namely, 60 tons of dry solids per 24 hours for each incinerator. They have on occasion satisfactorily handled an overload of approximately 33 per cent.
>
> (3) The incinerators have complied with the provisions of the specifications relative to freedom from nuisances due to fly ash, odors and smoke. Some difficulty was experienced during the tune-up period in complying with the specification requirement that the smoke be not heavier than Ringleman's Smoke Scale Chart Number One, but after certain corrections were made by the manufacturer, compliance with this part of the specification was attained. The sludge was reduced to a clean ash, the combustible content averaging 1.6 per cent.
>
> (4) The requirements of the specifications relative to meeting certain guaranteed costs were fulfilled. The actual costs during the 90-day acceptance period were $4,559.68, or $0.455 per dry ton, as compared with the guaranteed costs as stated in the proposal of $7,084.04, or $0.707 per dry ton. Translating these costs to an annual basis the actual costs of incineration would be $18,492.03, as compared with the guaranteed costs of $28,729.71, or an annual saving of approximately $10,000 over the guaranteed costs. It should be pointed out that the actual annual costs include an item of $4,725.00 for supplies and repairs which is the amount stated by the contractor in his proposal, and which sum was necessarily taken for purposes of comparison because no expenditures of any

TABLE II.—*Summary of 90-Day Test Data*

Item	Incinerator No. 1	Incinerator No. 2	Incinerator No. 3	Totals
Actual Days of Operation	58	62	66	186
Actual Hrs. of Operation	1,291.75	1,411.17	1,488.75	4,191.67
Total Tons Filter Cake Incinerated	8,602.7	9,608.7	10,031.4	28,242.8
Average Tons Filter Cake Incinerated/Hour	6.66	6.81	6.74	6.74
Average Moisture Content Filter Cake, Per Ct.	64.2	64.6	64.7	64.5
Total Tons Dry Solids Incinerated	3,076.7	3,403.7	3,536.6	10,017.0
Average Tons Dry Solids Incinerated/Hour	2.38	2.41	2.38	2.39
Total Tons Moisture Evaporated	5,526.0	6,205.0	6,494.8	18,225.8
Average Tons Moisture Evaporated/Hour	4.28	4.40	4.36	4.35
Average Combustible Solids, Per Ct.	58.1	57.2	58.4	57.9
Total Tons Combustible Solids	1,786.4	1,948.0	2,064.5	5,798.9
Average Tons Combustible Solids/Hour	1.38	1.38	1.39	1.38
Fuel Oil—Gallons	777	1,501	1,015	3,293
Gals. Used per Ton Wet Cake, Oil	0.09	0.16	0.10	0.117
Gals. Used per Ton Dry Solids, Oil	0.25	0.44	0.29	0.329
Gals. Oil Used per Hour Operation	0.60	1.06	0.68	0.786
Electric Power (KWH)	51,307	52,827	59,181	163,315
KWH Used per Ton Wet Cake	5.96	5.50	5.90	5.78
KWH Used per Ton Dry Solids	16.7	15.5	16.7	16.30
KWH Used per Hour Operation	39.7	37.4	39.8	39.96
Manhours Skilled Labor	84½	91	97¾	273¼
Manhours Semi-Skilled Labor	14	15	15	44
Manhours Unskilled Labor	628⅝12	675⅞12	715⅞12	2,019⅞12

magnitude were made by the District during the relatively short acceptance period. There does not appear any question that the costs of labor, fuel, oil and electric power will always be considerably less than those guaranteed by the contractor. While there is some uncertainty as to the cost of supplies and repairs, the actual cost can only be demonstrated over a period of years. The contractor's bid shows 1½ per cent of the construction cost for this item, or $4,725.00 annually, and the specification provided for the use of this amount in calculating guaranteed and actual costs. In view of the further fact that the total of all items comprising the guaranteed cost is to be used as a basis of determining compliance with the specifications, the actual cost of supplies and repairs can be as much as the sum of $4,725.00 and the saving of $10,237.68, or a total of approximately $15,000.00 annually, and still, the specifications would be complied with. It does

TABLE III.—*Comparison of Actual and Guaranteed Operation and Maintenance Costs During Ninety-Day Test Period from December 17, 1938, to March 17, 1939*

Item	Unit Price	Number of Units		Total Cost	
		Actual	Guaranteed	Actual	Guaranteed
(1) Labor					
(*a*) Skilled	$1.20	273¼	—	$ 327.90	—
(*b*) Semi-skilled	.90	44	—	39.60	$1,649.53
(*c*) Unskilled	.625	2,019⅞12	—	1,262.24	—
(2) Fuel Oil	.04	3,293	42,373	131.72	1,694.92
(3) Electric Power	.01	163,315	257,452	1,633.15	2,574.52
(4) Supplies	—	—	—	265.07*	265.07*
(5) Repairs	—	—	—	900.00*	900.00*
Total				$4,559.68	$7,084.04
Tons Dry Solids Incinerated				10,017	10,017
Cost per Dry Ton				$0.455	$0.707

* At 90/365 of guaranteed prices of $1,075 and $3,650, respectively.

not seem likely that the cost of supplies and repairs will approach this figure over a period of years, and therefore full compliance with the guaranteed costs from this standpoint is indicated.

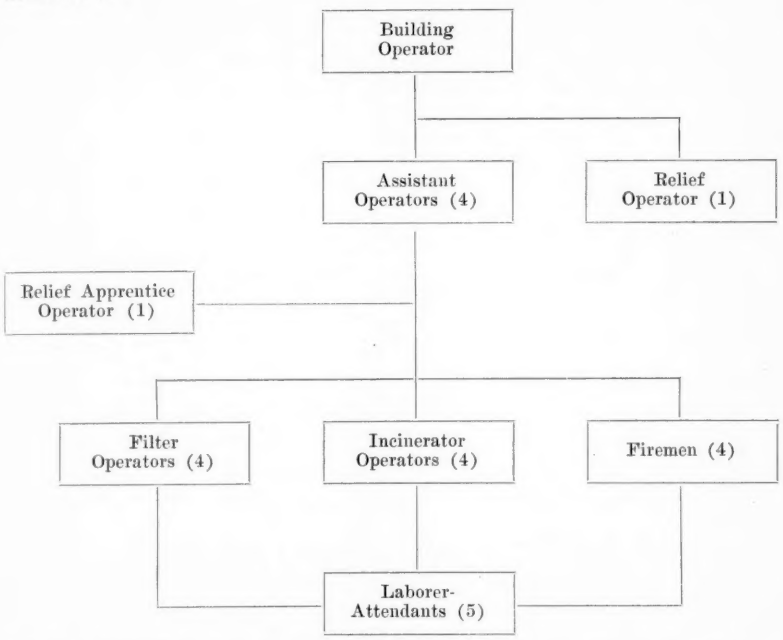
From July 21, 1938, to August 31, 1939, a total of 102,114.9 tons of filter cake was incinerated. The average B.T.U. per pound of combustible solids in the sludge during this period was 10,800 and the average volatile solids in the dry sludge cake during the year covered herein amounted to 56.0 per cent. The sludge cake was reduced by incineration to an ash containing less than 2 per cent volatile matter. As shown in Table IV, the moisture content in the sludge cake as produced by the filters has averaged 64.2 per cent during the period from December to August, inclusive. Including the water added to control temperatures in the incinerators the cake as incinerated averaged 66.9 per cent moisture during this same period.

The quantity of material incinerated in comparison to the capacity of the incinerators is interesting. Over a 24-hour period a maximum of 523.8 tons of filter cake or a total of 215.77 tons of dry solids has been incinerated. The capacity of each of the three incinerators is 60 tons of dry solids per 24 hours. As much as 78.5 tons of dry solids have been incinerated in one incinerator in a 24-hour period. Hourly rates considerably in excess of the above have been successfully handled. For the nine-month period from December 1, 1938, to August 31, 1939, the average number of tons of dry solids incinerated per day in each incinerator has averaged 59.1 tons as compared with the maximum guaranteed capacity of 60 tons daily.

During the nine-month period from December, 1938, to August, 1939, a total of 71,749 gallons of fuel oil were required by the incinerators.

Practically all of this was required in bringing furnaces up to temperatures from a cold condition and in holding temperatures in furnaces out of service. The above quantity of oil amounts to an average of 2.4 gallons per ton of dry solids incinerated. Power required for incineration amounted to an average of 16.5 K.W.H. per ton of dry solids.

Staff Required to Operate.—The Filtration and Incineration Building is under the direction of a building operator who normally is present only during the day shift. Under him are assistant operators, etc., as follows:



The total staff in this building numbers 24 men. The time of the relief operator and relief apprentice operator and the firemen cannot all be charged to the Filtration and Incineration Building. Only such time as is actually spent in this building is charged to sludge disposal. The above staff is organized for continuous twenty-four hour operation.

Cost Features.—(*a*) Construction Cost. The construction cost of sludge disposal facilities at the Minneapolis-Saint Paul plant are approximately as follows:

(1)	Concentration Tanks	$ 44,000.00
(2)	Filtration and Incineration Bldg.	402,000.00
(3)	Vacuum Filters and Appurtenances	101,150.00
(4)	Incinerators and Appurtenances	340,282.55
(5)	Piping and Miscellaneous Mechanical	86,600.00
(6)	Electrical	69,200.00
(7)	Chemical Feeding and Loading Equipment	25,511.00
	Total Construction Cost	$1,068,743.55

TABLE IV.—*Data on Sludge Incineration*
Nine Months Ending August, 1939

Month	Tons of Sludge Incinerated		Dry Tons per Incinerator Day	Gallons Oil Used	Power K.W.H.	Per Cent Dry Solids	
	Cake Basis	Dry Basis				In Cake Produced by Filters	In Cake as Actually Incinerated
December, 1938	9,826.4	3,346.5	53.8	7,573	—	34.2	30.8
January, 1939	10,119.0	3,654.5	60.4	4,195	54,782	36.1	34.6
February	8,663.2	3,022.3	56.6	6,069	50,943	34.8	33.2
March	8,851.9	3,439.5	61.3	6,793	55,829	39.1	34.8
April	9,398.7	3,321.6	61.4	5,634	54,205	35.0	34.0
May	9,932.2	3,579.9	61.5	10,470	61,569	35.3	32.2
June	9,528.9	3,649.1	64.0	6,188	55,572	38.3	34.1
July	8,479.3	3,007.7	57.5	10,763	52,061	35.3	32.1
August, 1939	8,348.5	2,847.6	55.0	14,064	52,069	*33.9*	*31.7*
Totals	83,138.1	29,868.7		71,749			
Average	9,250.0	3,320.0	59.1	7,970	54,629	35.8	33.1

A portion of the Filtration and Incineration Building is utilized for other purposes not directly associated with sludge disposal. This part is estimated at less than 20 per cent of the total cost of the building. The total first cost of about $1,000,000.00 for the sludge disposal portion of the plant, compares with a total plant cost of approximately $3,750,000.00.

(*b*) Operation and Maintenance Cost. Because of difficulties with the incinerators during the first several months of operation, costs during this period are not representative, and for this reason cost data is presented for the period from December 1, 1938, to August 31, 1939, only. Operation and maintenance costs of sludge disposal for this nine-month period are shown in Table V.

The operation and maintenance cost of filtration during this period when 28,434 tons of dry sewage solids, equivalent to 83,153 tons of filter cake, were disposed of was $81,046.48 and of incineration $29,720.29. Of the total cost of sludge disposal of $110,766.77, operation amounted to 90.8 per cent and maintenance 9.2 per cent of the total cost.

The costs per ton of dry sewage solids handled during various periods are as follows:

Vacuum Filtration
Cost per ton of dry sewage solids since December 1 ..... $2.85
Cost per ton of dry sewage solids for last six months 2.35
Incineration
Cost per ton of dry sewage solids since December 1 ..... 1.05
Cost per ton of dry sewage solids for last six months 0.95

TABLE V.—*Operation and Maintenance and Units Costs of Sludge Filtration and Incineration Nine Months Ending August, 1939*

	Operation and Maintenance Cost			Tons Sludge		Operation and Maintenance Cost per Dry Ton		
	Vacuum Filtration	Incineration	Total	Dry Sewage Solids Basis	Cake Basis	Vac. Filtration	Incineration	Total
December, 1938	$13,737.75	$ 5,680.77	$19,418.52	3,067	9,826.4	$4.48	$1.85	$6.33
January, 1939	10,594.05	2,716.65	13,310.70	3,150	10,119.0	3.37	0.86	4.23
February	9,334.35	2,977.01	12,311.36	2,920	8,663.2	3.19	1.02	4.21
March	8,364.06	2,800.75	11,164.81	3,755	8,851.9	2.22	0.75	2.97
April	8,095.15	2,444.49	10,539.64	3,065	9,398.7	2.64	0.80	3.44
May	8,021.87	2,960.57	10,982.44	3,339	9,932.2	2.40	0.89	3.29
June	9,178.08	3,179.92	12,358.00	3,727	9,528.9	2.46	0.86	3.32
July	7,239.88	3,630.36	10,870.24	2,818	8,479.3	2.57	1.29	3.86
August, 1939	6,481.29	3,329.77	9,811.06	2,593	8,348.5	2.50	1.29	3.79
Totals	$81,046.48	$29,720.29	$110,766.77	28,434	83,153	$2.85	$1.05	$3.90
Operation	$74,726.69	$25,798.19	$100,524.88	—	—	$2.63	$0.91	$3.54
Maintenance	$ 6,319.79	$ 3,922.10	$ 10,241.89	—	—	$0.22	$0.14	$0.36

For the entire period of nine months the total cost per dry ton of dry sewage solids was $3.90. However, during the last six months the total costs were reduced to $3.30.

The distribution of expenditures during this same period are shown in Table VI. The main item of cost of vacuum filtration is material and

TABLE VI.—*Distribution of Operation and Maintenance Costs for the Period from December 1, 1938, to August 31, 1939*

Item	Vacuum Filtration	Per Ct.	Incineration	Per Ct.	Total	Per Ct.
A. Operation						
(1) Labor	$18,106.06	22.3	$15,681.94	52.8	$ 33,788.00	30.5
(2) Material and Supplies	49,554.66	61.2	3,183.68	10.7	52,738.34	47.6
(3) Power and Light	7,065.97	8.7	6,932.57	23.3	13,998.54	12.6
B. Maintenance						
(1) Labor	3,962.49	4.9	2,109.27	7.1	6,071.76	5.5
(2) Repairs, Replacements and renewals	2,357.30	2.9	1,812.83	6.1	4,170.13	3.8
C. Total	$81,046.48		$29,720.29		$110,766.77	
D. Cost per Month	9,005.16		3,302.25		12,307.41	
E. Cost per Ton Dry Sewage Solids	2.85		1.05		3.90	

supplies (chemicals and cloth, principally) which amounts to 61.2 per cent of the total cost. In the case of incineration labor is the principal cost item. Considering the entire cost of sludge disposal, labor and material and supplies constitute 78.1 per cent of the total cost of operation and maintenance.

It is interesting to compare the cost of sludge disposal with the cost of the entire plant. During the period from December 1, 1938, to August 31, 1939, the total operation and maintenance cost of sludge disposal was $110,766.77. For the same period the cost of operation and maintenance of the entire plant, including administrative and supervisory expenses, was $231,486.48. Sludge disposal in this project constitutes about 50 per cent of the total cost of administration, operation and maintenance of the intercepting sewers and treatment plant.

General.—The sludge disposal processes in the Minneapolis-Saint Paul plant have functioned satisfactorily and at comparatively low cost. No difficulties of any consequence were experienced in placing the vacuum filtration portion of the process in operation and such difficulties as presented themselves in connection with incineration were successfully overcome by the contractor before acceptance tests were allowed to be begun.

The developments which have been made in sludge disposal methods in the last several years have resulted in a clean and satisfactory process being available to sanitary engineers. Regardless of the type and manufacture of the various sludge disposal equipment used in connection with sludge conditioning, filtration and incineration, it should be recognized that this type of process is a relatively complicated mechanical one, the projected use of which in connection with smaller plants where highly competent operation and maintenance staffs may not always be available, should be carefully considered. Other simpler processes may result in more continuous and dependable operation of the plant as a whole.

This brings up the matter of desirability of having a sufficiently large number of units with appropriate standby, arranged in a flexible manner to insure dependability of operation. This question is tied in with the provisions which have been made for storing sludge in some manner to permit of shutting down the equipment for routine maintenance or repair work. The Minneapolis-Saint Paul plant is particularly fortunate in having a layout which provides rather complete flexibility and dependability as evidenced by the fact that, since the incinerators were placed in regular operation late in November, the sludge disposal process has always been able to handle the load placed on it by the treatment processes.

While marked developments have been made in sludge disposal processes in the last five to ten years, it is the author's prediction that the advances which will be made in the next decade, both in the improvement of present processes and the development of new ones, will

far outshadow those which have been made in the past. The possibilities stand out as a challenge to the ingenuity of sanitary engineers.

The Minneapolis-Saint Paul Sanitary District is under the direction of a Board of Trustees of seven members with the author as Chief Engineer and Superintendent. In charge of plant operation are C. R. Raiter, J. C. Sager, W. H. Sleeger and B. M. Storey. Mr. K. L. Mick is Chief Chemist and S. J. Larsen is Mechanical Engineer. S. E. Linsley is Building Operator in charge of Filtration and Incineration.

FILTRATION AND INCINERATION AT BUFFALO*

By C. R. Velzy

Superintendent, Sewage Treatment Works, Buffalo, N. Y.

Description of Project.—Somewhat over thirty years ago, recognition of the pollution of international waters led to the signing of a treaty in 1909 between the United States and Canada providing for the appointment of the International Joint Commission. The duties of this Commission were to study the extent and causes of the pollution of boundary waters and to recommend possible remedies for this pollution.

The first report of this Commission was made in 1914. There followed numerous discussions and hearings until the work was interrupted by the World War in 1917. The project became active again in 1928 and in April 1935 the Buffalo Sewer Authority filed an application with P.W.A. for a loan and grant, which application was approved.

There are two major objectives to be accomplished by the sewage disposal project at Buffalo. First, the pollution is to be removed from the Niagara River in order to protect the water supplies which are drawn from the river below Buffalo, and also in order to satisfy the requirement of removing pollution from international waters. The second objective is to remove pollution from Buffalo Harbor, and from the Buffalo River which flows through the southern part of the city.

The water intakes for the cities of Tonawanda, Lockport, and Niagara Falls, are all on the Niagara River just below Buffalo. Below the Falls, other cities take their water supply from the River and it has been stated that the pollution from Niagara River has been noticeable as far as Rochester on Lake Ontario.

Pollution is removed from the Harbor and the Buffalo River by the intercepting sewer, consisting of a northerly branch and a southerly branch running in general parallel to the water front and joining at a point opposite what is known as Bird Island. From this point the interceptor is carried through an inverted syphon under the harbor and to the main pumping station on the island.

The intercepting sewer varies in size from 24 in. in diameter to an 11-ft. 6-in. semi-elliptical section. The total length is somewhat over 13 miles, of which approximately 20,900 ft. is in rock tunnel, about 4,100 ft. in earth tunnel and the rest in open cut. There are two outlying pumping stations serving low-lying areas in the south and southeast portions of the city.

The treatment works, located on Bird Island, is designed to provide a treatment adequate for the needs of the Niagara River and to accomplish a satisfactory and economical disposal of sludge. Its main features are briefly described in the following paragraphs.

* Presented at the Twelfth Annual Meeting of the Central States Sewage Works Association, Chicago, Ill., Oct. 12, 1939.

The Main Pumping Station is equipped with six vertical, centrifugal pumps of 120 M.G.D. nominal capacity, driven by 550 h.p. synchronous motors.

The screens and grit chambers are combined in one structure. The screens have a ¾-in. clear spacing and are equipped with mechanical rakes. The screenings are passed through grinders and are then discharged back into the sewage. The grit chambers consist of 12 rectangular channels equipped with conveyor type mechanisms to continuously remove the grit. Bucket elevators and washers lift the grit from

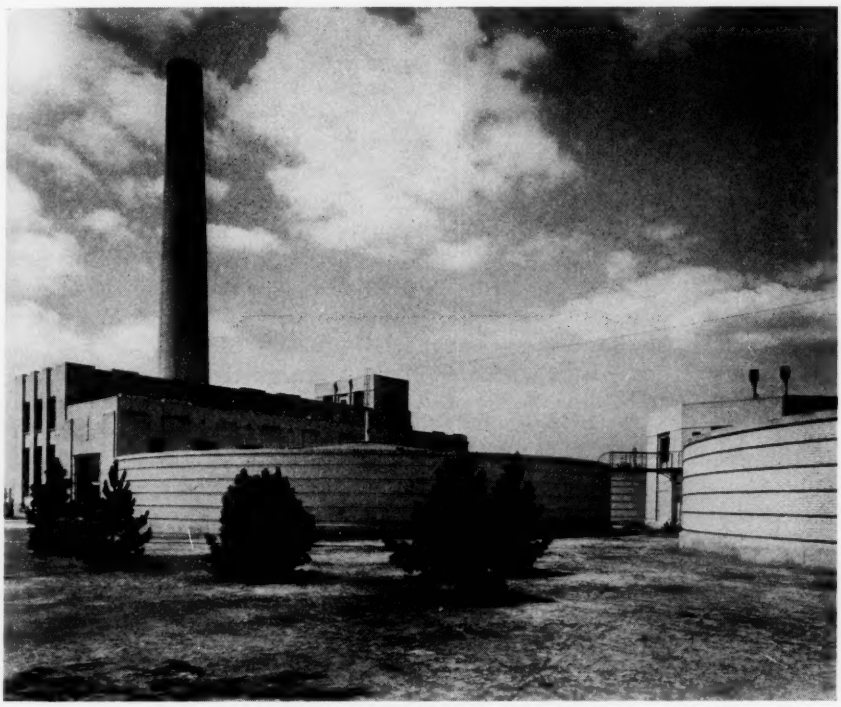


FIG. 1.—Sludge disposal building with sludge tanks in foreground.

the channels, remove some organic matter and discharge the grit to the loading room from which it is trucked to the dump or to the incinerators.

The sewage is chlorinated just before entering the four circular sedimentation tanks, which are 160 ft. in diameter and 15 ft. deep. From these tanks, the disinfected sewage is discharged into the Niagara River.

The sludge from the sedimentation tanks is pumped into four sludge tanks, 90 ft. in diameter and 28 ft. deep at the side wall. The gas produced by partial digestion in these tanks is collected under floating covers and used for fuel. From the sludge tanks the sludge flows

or is pumped to the sludge disposal building which houses vacuum filters and incinerators for the dewatering and burning of the sludge.

There are three filters each with 500 sq. ft. of filter surface and with a nominal rating of 100 tons of 70 per cent. moisture sludge cake in 24 hours. The three incinerators have the same nominal capacity as the filters. The sludge cake is discharged from the filters to one conveyor belt, is carried across the building and over the weightometer by a second belt, and is distributed to the incinerators by a third belt. Flexibility of operation is thus provided, it being possible to operate any combination of filters and furnaces.

Bases of Design.—The present population of Buffalo is about 600,000. Design was based on a predicted population of 750,000 in 1950 and 1,100,000 in 1985.

The dry weather flow was determined to be 200 gals. per capita per 24 hours. The intercepting sewer was designed for 1985 conditions and for 2½ to 3 times the dry weather flow or a maximum of 570 M.G.D. The main pumping station and screen and grit structures, being difficult to enlarge, were also designed for this maximum flow. Sedimentation and sludge disposal were designed for 1950 conditions, or a dry weather flow of 150 M.G.D.

The detention period in the settling tanks was established as 80 minutes at a flow of 150 M.G.D., providing about 50 per cent removal of the suspended solids.

It was estimated that chlorine should be applied at a rate of about 7 p.p.m. while a total capacity of 30,000 lbs. per 24 hours was provided to meet high demands. Provision was made to apply chlorine prior to settling so as to obtain a contact period in the settling tanks.

The design of sludge disposal structures and equipment was based on a content of suspended solids in the raw sewage of 180 p.p.m. or 0.30 lb. per capita per day and a removal by settling of 50 per cent. This produces 90,000 lbs. per day of solids on the dry basis. It was further estimated that the 20 days time in the sludge tanks would reduce this quantity of solids by digestion to 60,000 lbs. Thus there would be 30 tons of dry solids per day to dewater and incinerate which was estimated to carry about 70 per cent of moisture, making 100 tons of sludge per day.

Sludge Disposal Operation.—The operation of sludge disposal processes at the Buffalo Treatment Works during the first year has been of particular interest because incineration is relatively new. Against a background of satisfactory general performance are noted several features of special merit as well as a number of interesting operating problems.

The sludge tanks, providing a storage period of about 20 days have been a definite asset. They absorb the irregularities of the daily production of raw sludge and bridge the interruptions in filtering and incineration. They permit a six-day operating week and a weekly cleaning and maintenance period. The gas resulting from digestion in the tanks has real value as fuel for heat and auxiliary fuel for incineration.

On the whole, the tanks provide a flexibility and smoothness in the operation of filtering and incineration which could not otherwise be obtained.

The vacuum filters have given exceptionally good results. At a rate of 5 lbs. of dry solids per sq. ft. per hour, each filter would yield 30 tons of dry solids per day or 100 tons of 70 per cent moisture cake. The highest production for one day from one filter was 220 tons of 63.6 per cent moisture cake which is a total of 160,700 lbs. or a rate of 13.4 lbs. dry solids per sq. ft. per hour. Monthly averages have run above 8.0 lbs. per sq. ft. per hour. These favorable filtering rates have been obtained during the first year with less than 10 per cent of lime and less than 3 per cent ferric chloride.

The incinerators and the drying apparatus have demonstrated their ability to burn sludge at rates somewhat higher than specified. During practically all of this first year, this equipment has been undergoing tests and adjustments by the contractor and its operation is now settling into a satisfactory routine.

One of the operating problems encountered was in connection with the pumping of raw sludge from the settling tanks to the sludge tanks. The sludge line is a 10-in. cast iron pipe about 600 ft. long. Although the normal pressure in this line is between 20 and 30 lbs. per sq. in., it was found that the pressures built up to 50 to 60 lbs. when pumping at high rates. Examination disclosed that the pipe was almost filled with grease. Steam and hot water were used to flush out the line and pressures returned to normal.

A number of questions arise from this experience. Has this happened in other plants? Should sludge lines be made small enough to provide scouring velocities and thus prevent deposits? Should sludge lines be of steel with expansion joints to better withstand steaming out?

This incident is also an example of the general need for more sturdy mechanical equipment in sewage treatment. The sludge pumps in this case were designed for 20 lbs. pressure, but would have been more satisfactory if designed for 50 lbs. or more. No doubt, competition tends to promote the development of light equipment. It appears worthwhile to give attention to specifying sturdiness in sewage plant machinery so that good manufacturers may find it possible to furnish more sturdy equipment.

An interesting and unexpected problem arose from the high rates of filtering. With a filter tending to produce well over 100 tons of cake per 24 hours, it was difficult to operate one filter and one furnace together. Operation of one filter with two furnaces was not so difficult. The high filter rate and the resulting thick, heavy cake produced wide fluctuations in the weightometer indicator and pen because of the tendency for the cake to drop on the belt in large pieces with empty spaces between the loads of cake.

It appeared that a device serving as a surge bin and a feeder would improve this condition. After inspecting an installation of this type at Auburn, New York, a device was built and installed on one filter

consisting of a bin with a screw conveyor in the bottom. The conveyor was driven through a variable speed drive. Improvement in the weightometer chart was noted and it became possible to regulate the load to the furnace with more precision and promptness and without regard to rate of filtering. A feeder of this type, with some improvements over the first one, is to be installed on each filter.

The major problem in incinerator operation appears to be the proper organization of maintenance work. This is largely a question of handling abrasion in certain parts of the drying and sludge handling equipment. This abrasion may be due to the presence of fine sand. Analyses of the sludge cake show about 23 per cent. of free sand, which we think is relatively high.

It was found that the bars in the flash dryer, the blades and casings of certain fans and the elbows in the fuel line would wear through in relatively short periods. The application of hard surfacing by arc welding has been employed to resist the wear at these critical points. Some progress is also being made toward providing easily replaceable parts where abrasion occurs.

It now appears possible that an operating and maintenance routine can be established which will provide that each furnace will operate for a period of about two months and will then be taken off the line for general overhaul with particular attention to the points subject to abrasion.

A new feature in our incinerator layout is the provision for burning of the grit. In addition to the problem of drying and incinerating grit, there was considerable attention given to feeding of the grit on to the sludge conveying equipment. A feeding machine was developed which receives the grit as it is dumped from the truck and discharges it to a bucket elevator. This elevator in turn drops it on to the last conveyor belt. The presence of coarse material in the grit appears to give trouble in the drying and sludge handling equipment. There is, therefore, under consideration the installation of a vibrating screen through which the grit will be passed before it reaches the grit feeding machine. With the addition of this equipment, it appears that the grit can be successfully handled in the incinerators.

As an example of one of the minor problems, there is the question of cleaning the conveyor belts to prevent the dropping of wet sludge cake in the basement of the Sludge Disposal Building. The unloading scrapers will not remove all the sludge cake from the belt so that the return flight fouls the rollers and also drops more or less cake to the basement floor. For the time being, a wood scraper has been applied as a belt cleaner at the point where droppings were most objectionable and at another point a steel scraper has been applied to keep one of the larger pulleys clean.

During the first few months of operation an accumulation of so-called top sludge was noted on the sludge tanks. The monthly inventories of the tanks showed this material to be six to eight feet deep. It was high in grease and analyzed as high as 15 to 20 per cent solids.

At times this top sludge accumulated to the extent of clogging the supernatant pipes. It was found possible to pump it out by connecting sludge pump suctions to the supernatant piping, and it is now our tentative practice to draw off small quantities of this material at regular intervals and pump it with the sludge to the filters for dewatering and burning.

A brief statement of sludge disposal operating results will summarize the first year of operation at Buffalo.

The per cent of solids in the raw sludge averaged 3.46 per cent. This relatively low solids content was due in part to the inexperience of the new operators. We are now pumping raw sludge at between 9 and 10 per cent solids. Digested sludge has averaged consistently about 12 per cent solids.

The per cent of moisture in the sludge cake averaged for the first year 61.8 per cent, and has been about the same during the last three months. The volatile matter during the first year averaged 38.8 per cent and is still running quite low. These results were obtained by the use of a 9.25 per cent lime and 2.31 per cent ferric chloride as averages for the first year, without much change in recent months.

The burning of sludge has been at the rate of 77 tons of filter cake per day with the use of about 6½ gallons of oil per ton during the first year. For the past three months two incinerators have been in use burning at the rate of 84 tons of cake per furnace per day. The cake has contained 38.5 per cent solids which amounts to a rate of 32.3 tons of dry solids per day. Gas is now being used as auxiliary fuel and the rate has been about 850 cu. ft. per ton of wet cake.

The results of incinerator operation, in particular, cannot be considered as representative because of the numerous interruptions and the irregularities resulting from the testing and adjustments to the equipment.

At present, what appears to be a satisfactory routine for filtering and incinerator operation has been established and personnel has been trained in the handling of the various processes. The second year of operation promises to be relatively normal and should yield operating results in all departments representative of what can be expected from the Buffalo plant.

SEWAGE TREATMENT AT GARY *

By L. R. Howson

Alvord, Burdick and Howson, Consulting Engineers

Gary is located at the south end of Lake Michigan, approximately twenty-five miles from the Chicago loop. It occupies the easterly end of the so-called Calumet District, which extends from the Indiana-Illinois line eastward. This area has a present population of approximately 300,000 people. It is essentially industrial, embracing some of the country's largest steel mills, oil refineries, and other heavy industrial developments.

The disposal of the sewage of the Calumet area is intimately associated with the metropolitan Chicago problem, due to the fact that the sewers of this area in general discharge into the Little Calumet and Grand Calumet rivers. These rivers in turn discharge into Lake Calumet or through the Sag Channel to the Main Channel of the Chicago Sanitary District and thence into the Illinois River.

Gary being the most easterly of these cities presents a waste disposal problem differing somewhat from the others. Its sewers up to the present time have discharged almost exclusively into the Grand Calumet river which heads up at Gary and flows westerly (Fig. 1). It originally joined the Little Calumet in Illinois and flowed into Lake Calumet and thence into Lake Michigan at South Chicago. The dredging of the Indiana Harbor ship channel resulted in the discharge of most of the Gary sewage into Lake Michigan about six miles southeasterly from the mouth of the river at South Chicago. The Gary problem, therefore, under present conditions of flow, is more directly related to the production of an effluent satisfactory for discharge into Lake Michigan, from which all of the water supplies of both the Calumet area and the City of Chicago are drawn, than to the requirements of the restricted flow through the channels of the Chicago Sanitary District.

Population and Sewage Flow.—Gary has had a very rapid growth in population. The city was started slightly over thirty years ago and in that period has witnessed a transition from sand dunes and marshes to a city of 115,000 people. In the first twenty-five years it reached a population in excess of 100,000 and prior to the depression was experiencing a growth of approximately 5,000 per year. Since 1930 growth has been materially slowed up. It is estimated that the present population is 115,000 (Fig. 2).

The sewage flow at Gary as measured in terms of per capita flow is relatively large and the strength of the sewage correspondingly weak. Under the most recent gagings of about a year and a half ago the average dry weather flow was 21.25 m.g.d. with an average five day B.O.D. of 111 p.p.m., the equivalent of .17 pounds of B.O.D. per capita per

* Presented at the Twelfth Annual Convention of the Central States Sewage Works Association, Chicago, Ill., Oct. 13, 1939.

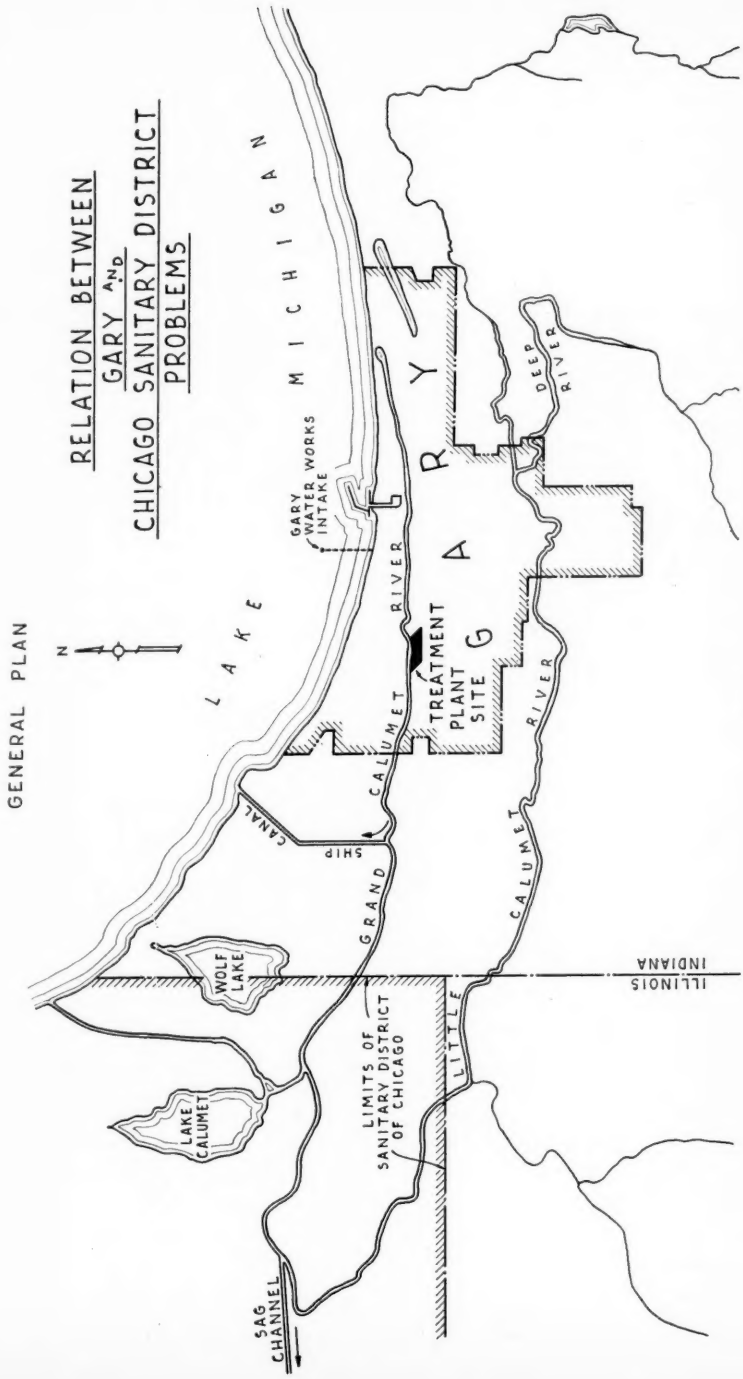

RELATION BETWEEN
GARY AND
CHICAGO SANITARY DISTRICT
PROBLEMS
GENERAL PLAN
N
LAKE MICHIGAN
GARY WATER WORKS INTAKE
CALUMET RIVER
TREATMENT PLANT SITE
GARY
DEEP RIVER
SHIP CANAL
GRAND CALUMET RIVER
WOLF LAKE
LAKE CALUMET
LIMITS OF SANITARY DISTRICT OF CHICAGO
LITTLE CALUMET RIVER
ILLINOIS
INDIANA
SAG CHANNEL

FIG. 1.

day. Of this total flow approximately half represents sewage and the other half infiltration of ground water into the sewers. The entire city is constructed in lake sand and practically all sewers are built below the static water level. Due to the sandy nature of the soil, the rainfall largely percolates into and through the sand to the sewers, thus providing a large and unusually well sustained flow.

Measurements and analyses of the sewage were made in 1928 and in 1937. During that period the quantity increased about 10 per cent but the total B.O.D. strength increased 38 per cent, with a per capita increase of 20 per cent.

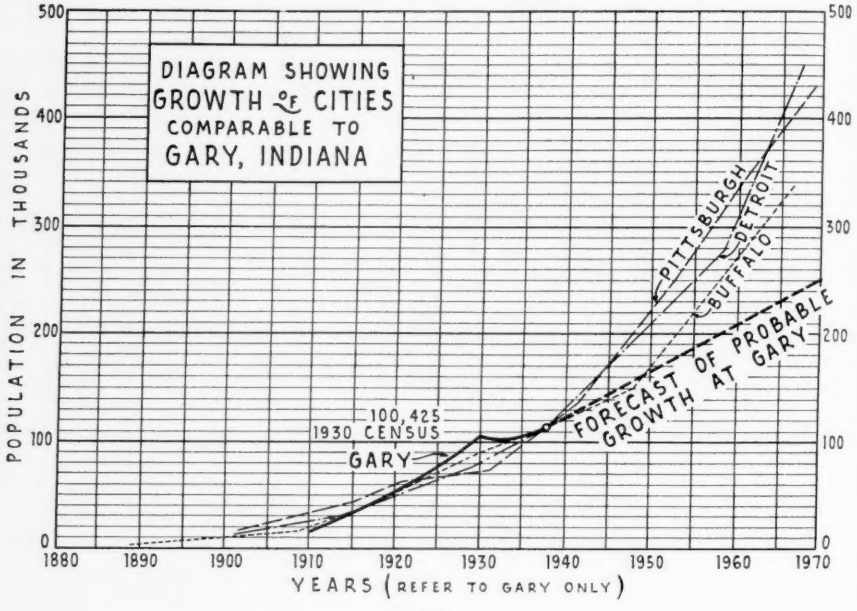


FIG. 2.

Industrial Wastes.—The principal industries in Gary are related to the production of steel. Aside from the pickling liquor wastes, which carry considerable amounts of acid and ferrous sulfate, the water discharged into the Grand Calumet by the industries is almost entirely used for cooling purposes. It is substantially Lake Michigan water with a very low B.O.D. and not requiring treatment.

The acid pickling liquor wastes are sterile; their volume is approximately 3,250,000 gallons per day. These wastes are discharged into the same outfall sewers that carry about ten times this volume of condensing water, which being Lake Michigan water has sufficient alkalinity to partially neutralize the acidity of the wastes. This combined flow of approximately 35 m.g.d. is discharged into the Grand Calumet river, the flow of which is largely made up of condensing and cooling water of the Carnegie-Illinois Steel Mill, which normally averages

about 400 million gallons daily, thus still further diluting by about 10 to 1 the already diluted acid wastes. The alkalinity in this total dilution of about 100 to 1 is more than sufficient to neutralize the acidity of the industrial wastes.

In view of the very slight benefits of neutralizing the acidity of the waste by lime rather than by the alkalinity of the diluting water, it was decided that no treatment of the industrial wastes at Gary was warranted other than that the sanitary flow from the mills should be separated from the remaining flow and discharged to the sewers leading to the sewage treatment plant.

Requirements for Treatment.—With the effluent discharging to the lake through the ship channel, a high degree of treatment of the sanitary sewage will be required throughout the entire year. The effluent must be low in bacteria, stable, and free of settleable solids.

In determining the type of treatment for Gary, financial comparisons were made of:

(*a*) Trickling filters.
(*b*) Chemical precipitation followed by trickling filters.
(*c*) Activated sludge.
(*d*) The Guggenheim process.

The following table shows the results of this financial comparison. The annual costs assume P.W.A. assistance in financing to the extent of 45 per cent.

Type of Treatment	Cost to Construct	Annual Cost	
		Based on 110,000 People, 25 M.G.D.	Based on 170,000 People, 40 M.G.D.
Trickling Filters	$1,948,000	$ 99,220	$113,220
Chemical Precipitation and Trickling Filters	1,760,000	119,350	144,700
Activated Sludge	1,926,000	128,665	147,465
Guggenheim Process	2,112,000	138,230	165,380

After a consideration of the costs of construction and of operation, the character of effluent, the isolation afforded by the available site, and the effect of the sewage treatment plant upon adjacent property values, it was decided to construct a plant of the activated sludge type.

Factors Affecting the Design.—Before proceeding with a discussion of the design of the plant, which is now under construction, it may be helpful to briefly call attention to some of the factors which influenced the layout and the capacities and types of the various units.

The Calumet is an intensely industrial area. It is axiomatic that industries draw other industries to a locality. While the industries presently at Gary produce no waste which complicates the sewage disposal plant design, it is believed prudent to design liberally so as to be

able to successfully treat a stronger waste than is now represented by the Gary sewage.

Gary, until the depression, was a rapidly growing city. There is every reason to believe that this growth will eventually be resumed. In 1928 it was estimated that by the present time the population would have reached 180,000 people. The depression has simply retarded that growth and it is now believed prudent to design for 170,000 people, which it is believed will probably be resident in Gary some time between 1950 and 1960.

The Gary work is being financed under the Indiana Sanitary District law. The present work, including sewer construction, will exhaust the District's financing ability. The plant is liberally designed in view of financial difficulties surrounding future enlargement.

Basis of Design.—The basis of design adopted is as follows:

Population	170,000
Average flow	40 M.G.D.
Peak flow through entire plant	60 M.G.D.
Settling and pumping capacities	90 M.G.D.
5 day B.O.D.	111 p.p.m.
Suspended Solids	120 p.p.m.

Intercepting Sewers.—Gary is sewered on the combined plan. All dry weather flow and part of the storm flow is intercepted and conducted to the treatment plant through two main intercepters, an 84 in. from the east and a 42 in. from the west. These join immediately in front of the pumping station in a junction manhole. Their invert elevations are approximately — 12 as referred to Lake Michigan datum. The ground at the site is at elevation + 12. From the junction manhole the combined flow passes to the screening chamber.

Excavation to 25 ft. below static water level would be very costly without the use of well points. However, with the fine sand found there it has been possible to lower the ground water table over the entire area of the work and once the storage was pumped out, to work in the dry, at a pumpage rate less than 100 g.p.m.

Screening Chamber.—The screening chamber houses five comminutors, each in an individual channel, the inlet and outlet to which are controlled by hydraulically operated sluice gates. The comminutors are so designed that when the maximum rate of flow of 60 m.g.d. is passing through the plant the loss of head, with all five units operating is specified as not exceeding 15 inches. The comminutors are 25 in. in diameter. The floor elevation of the channels is at — 12. Motors are set at floor elevation + 3. No bar screens are provided.

The comminuting equipment is housed in a concrete chamber built underground immediately adjacent to the pump and blower building. Outside access as well as inside doorway to the pump room is provided. Ventilation of the screening chamber is provided by an air-filter protected pipe connection to the suction channel of the blowers.

Pumping Equipment.—The raw sewage pumping equipment consists of five units, two electric motor driven units each of 15 m.g.d., and three gas engine driven units each of 20 m.g.d., a total installed capacity of 90 m.g.d. against 35 ft. total head. The pumps are of the horizontal shaft type erected on a floor the elevation of which is + 3. They will take suction from a channel directly underneath and will normally operate at a suction lift of from 14 ft. to 16 ft. On account of this high suction lift and in order to prevent cavitation, the specifications require low pump inlet velocities, specifying pump nozzles of 24 in. in diameter for the 15 m.g.d. and 30 in. in diameter for the 20 m.g.d. pumps. These result in inlet velocities of about 7 ft. per second.

The gas-engine driven units will be those normally operated. They will be automatically float controlled so that through regulation of speed the water level in the suction well will be maintained at a more or less constant elevation. While 20 m.g.d. is their rated capacity, they must operate satisfactorily over a range of from 15 m.g.d. to 25 m.g.d.

Each sewage pump is provided with an automatic cone type discharge valve. Pumps will be primed continuously. The motor driven pump switch circuits will be interlocked with the solenoid circuit of the discharge cone valve, and the priming valve switch circuit is connected with the motor control to prevent starting of the pump when not fully primed.

The priming valve switch of the gas-engine driven units is also interlocked with the engine ignition circuit so that the engine cannot be started unless the pump is primed and also interlocked with the cone valve solenoid circuit so that the valve will start closing immediately when the engine is shut down manually or otherwise.

In view of the pumps being located on the lower floor of the building, which houses immediately above them the offices and laboratory, it is essential that the pumps operate as free of noise and vibration as possible. It was accordingly specified that with the gas-engine driven units, the engine should be mounted on vibration dampers for the suppression of both noise and vibration. This is provided by spring vibration dampers. The pumps and gas engines are supplied by Worthington. The specifications are also quite rigid in specifying a maximum gas engine piston speed of 1,000 ft. per minute and maximum rotative speeds of 600 r.p.m.

Grit Chambers.—Grit chambers are provided in duplicate. They are of the mechanically cleaned grit washing type. The two chambers are designed for a one-minute detention period at rated capacity. Equipment is of the Link Belt type with drag line conveyors pulling the grit to a sump from which it is elevated by worm screw conveyors to an elevation which permits of discharge into dump cars. These cars travel over industrial tracks to the dump. The grit chambers themselves are not housed except at the upper end of the screw conveyors and the discharge into the cars.

Primary Settling Tanks.—A primary settling period of one hour is provided. Alternate designs were made for square clarifiers using

rotative equipment, and for rectangular basins using conventional drag line quipment. The combined cost of the square clarifier construction and equipment was lower than for the rectangular design and accordingly rotative equipment of the Dorr type was purchased.

The four primary clarifiers are of the central Sifeed radial flow type. The inlets to all four basins are at a common corner. An operating gallery extends east and west between the clarifiers. In this gallery are housed the sludge piping, drains, scum and incidental piping. The upper part of the gallery is the influent channel The effluent channel is under the floor of the gallery.

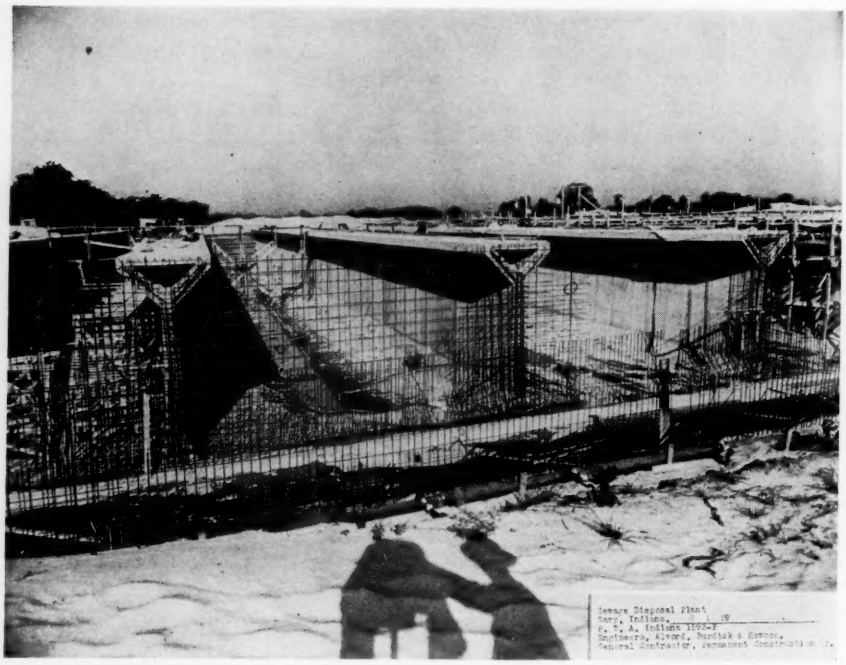


FIG. 3.

Aeration Tanks.—From the primary settlers the flow is to the aeration tanks which are ten in number, each 30 ft. wide by 15 ft. water depth and 300 ft. long (Fig. 3). Each aeration tank is provided with independent air, sewage, and return sludge connections each with its individual meter.

All piping, controls and meters are housed in an aerator control house extending along the entire 300 ft. width of the ten basins.

Basins are of the spiral-flow type with air diffusion through stationary diffusion tubes furnished and installed by the Chicago Pump Company. The tubes are 3 in. in internal diameter by 24 in. long, set 24 in. above the floor of the aeration tanks. They are staggered along the header so as to give a spacing of 1 ft. 4 in. There are 225 tubes

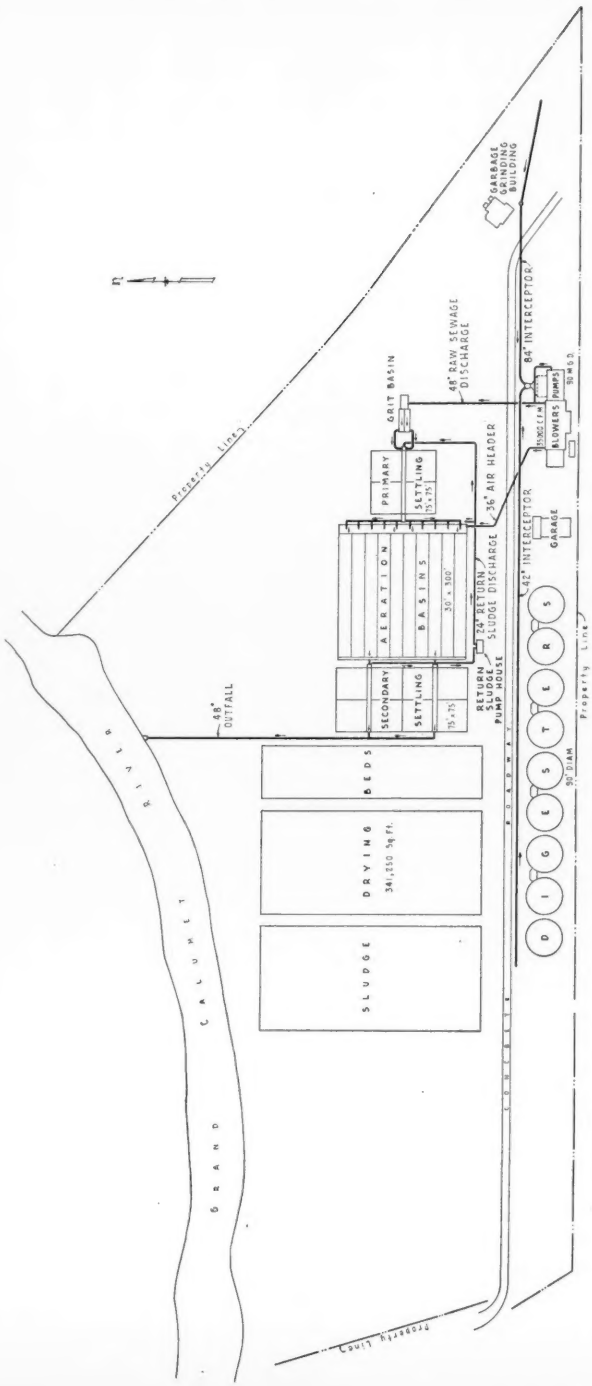


FIG. 4.—General Plan, Gary Sewage Treatment Plant.

in each 300 ft. tank. The permeability rating of tubes is 40. The design is based upon a normal use of air at the rate of 0.4 of a cubic foot of air per gallon of sewage, with sufficient capacity provided in the air header and the tubes to take care of one cu. ft. per gallon. The retention period in the aeration tanks is five hours for the sewage plus 25 per cent return sludge.

Factors affecting the selection of fixed tubes instead of plates for air diffusion at Gary include:

(1) A saving in initial cost estimated at $15,000.
(2) Some saving in annual cost due to 2 ft. less head on the blowers.
(3) Advantages during periods when tanks are out of service as will frequently be the case at Gary in the early years.

Secondary Settling Tanks.—The secondary settling tanks are substantially duplicates of the primary tanks, except that double the capacity is provided in two batteries of four tanks each. Expressed as retention period, two hours is provided, the equivalent of a settling rate of approximately 900 gal. per sq. ft. per day. Each tank has 300 lineal feet of overflow weir.

Digesters.—At the time bids were taken, alternate designs were prepared for fixed cover digesters with mechanical mixing equipment of the Dorr type, and Pacific Flush tank type floating covers. On the combined bid for the construction and equipment, the fixed covers were lower in cost and were adopted.

The installation consists of six circular digesters 90 ft. in diameter with a side wall depth of 20 ft. Each digester has a nominal capacity of 125,000 cu. ft. Four of the digesters are provided with fixed concrete roofs. The other two have floating covers with gas storage of approximately 70,000 cu. ft. each. The tanks are so arranged that they may be operated either as four primaries and two secondaries, or three each of primary and secondary.

Each pair of tanks is provided with a control house in which are located all of the valves, sludge pumps in duplicate, and the necessary facilities for temperature observations, gas metering, observations of sludge concentration, etc.

The roofs of the fixed cover digesters are of flat slab on columns of reinforced concrete construction, which comparative figures indicated are materially less costly than the all steel construction of the Dorr Company. All digesters are surrounded with earth embankments for insulation and the roofs of the four fixed cover tanks have a 12 in. earth cover as well.

All four tanks which may be used as primary are provided with circumferential heating coils which consist of five coils of 1½ in. pipe supported by brackets so as to be 24 in. from the face of the outside wall. Circulating water is provided by pumps using the cooling water from the gas engines and also connected to hot water gas fired boilers.

In each of the four primary tanks, there are installed two Dorr Company turbo-mixers, each of which has an impeller at the bottom and a scum breaking propellor at the top of the shaft.

The total sludge digestion capacity is equivalent to 4½ cu. ft. per capita for the 170,000 population design capacity.

Blowers.—It is estimated that there will be somewhat more gas than will be required for pumping but that most of the air compressing will be done by electric power. The large per capita flow of sewage will require more than the usual amount of gas for pumping.

Five blower units are provided as follows:

1—5,000 c.f.m. motor driven Elliott centrifugal.
1—7,000 c.f.m. " " " "
1—9,000 c.f.m. " " " "
2—7,000 c.f.m. gas engine driven Connersville blowers.

All blowers take air from a suction conduit under the floor. The Connersville units are provided with Burgess silencers on the suction.

Air is filtered through a movable oil bath filter followed by sectional cloth filters made by the American Air Filter Company. Under design conditions the velocity of the air through the cloth filters will be about 1 ft. per second. The velocity in the suction channel will normally be about 5 feet per second except as restricted by piping. All units are specified with large inlets so as to reduce air inlet velocities to not to exceed 50 ft. per second.

In order to minimize vibration and noise the motor driven centrifugal units are set on a concrete pad separated from the floor system by 2 in. cork vibration dampers. The gas engine driven Connersville units rest on concrete pads supported by spring vibration dampers. All piping is provided with rubber expansion joints and all minor piping and conduit connections are flexible.

Sludge Drying.—The entire sewage treatment site is of fine lake sand extending to considerable depth. This fact makes it unnecessary to underdrain the sand beds, the construction of which, therefore, essentially consists only of a careful grading of the sand on which is laid an industrial track. The total sludge bed area of 340,000 sq. ft. (2 sq. ft. per capita) is divided into 65 beds each 42 ft. by 125 ft. Two lines of 24 in. gage industrial track are laid the length of each bed, spaced 22 ft. apart. Bed separators are of 2 in. by 14 in. creosoted plank set in concrete posts.

The industrial track from all beds is connected through suitable ladder tracks so as to permit dumping sludge either for waste or on a concrete loading platform, which is provided to facilitate the loading of the sludge into trucks. It is anticipated that at Gary there will be a real demand for sludge as with the drifting character of the sand surface it is necessary to haul in large quantities of black dirt for topping. The sludge will be excellently adapted for this use.

A gasoline locomotive designed to haul ten ⅔ cu. yd. loaded cars is provided, also a ½ cu. yd. caterpillar clam shell to transfer the sludge from the loading platform to trucks.

Return Sludge Facilities.—Return sludge pumps are housed in a separate pumping station located near the final settling tanks. The equipment consists of one 3 million, one 5 million, and one 7 million

centrifugal pump motor driven. These pumps discharge through a 24 in. main to the primary settlers and to the aeration tanks. The quantity is controlled through a master meter and individual meters so as to be properly distributed to the several points.

Architectural Features.—Gary being the heart of the steel and cement industry, it was decided to make all superstructures of reinforced concrete. The main building houses the pumps, blowers, laboratory, and all offices. This building is approximately 235 ft. in length. It is designed of monolithic construction, heavily reinforced to distribute, in so far as possible, expansion and contraction stresses, and is built without joints of weakness. The main entrance, and openings leading therefrom, have doors of stainless steel construction.

In view of the fact that the administration office and laboratory are located in the same building with the pumping and blower equipment, every precaution has been taken to minimize vibration and noise. In addition to the special vibration dampers installed in connection with equipment as previously described, all ceilings in the equipment rooms, office and laboratory section have acoustical title ceilings.

All floors in equipment rooms are of quarry tile. Walls are of buff terra cotta. In the laboratory and offices the floor is covered with rubber tile The wall finish is of plaster in the offices and tile in the laboratory.

A separate structure provides storage for 12 automobiles, toilet and shower facilities for the employees.

The water used about the plant will be purchased from the Gary Heat, Light and Water Company through a 4 in. line leading from the Company's mains about one-half mile distant from the plant site. All water used around the plant for other than drinking and laboratory purposes discharges through an open connection into a receiving tank and is thence repumped so as to prevent back-siphoning and possible pollution.

Cost.—The cost of the sewage treatment project exclusive of the garbage disposal is as follows:

Contractor and Work	
Permanent Construction Co.—All structures and piping except administration and blower building and garage	$ 967,600
Dorr Company—Clarifying and digestion equipment	116,000
Pacific Flush Tank—Sludge pumps	2,882
Strandberg & Spencer, Inc.,—Administration and blower building, garage, etc.	422,883
Fairbanks Morse—Return sludge pumps	3,460
Elliott Co.—Blower equipment	133,610
Gary Office Equipment—Furniture	3,933
A. Daigger & Co.—Laboratory equipment	2,085
Worthington—Raw Sewage pumps	45,090
Chicago Pump Co.—Comminutors	18,000
Total	$1,715,543

Equivalent to $42,816 per M.G.D. capacity.

Garbage Disposal.—Under the Indiana Sanitary District law, the Board of Commissioners is charged with disposal of the garbage as well as the sanitary wastes. The Board accordingly instructed its engineers to make a report upon the most practicable means of caring for the Gary garbage. Their report recommended that "The least expensive and the best plan for garbage disposal for Gary would be to grind the garbage into the sewers for disposal with the sewage . . . and that the remaining combustible refuse should be burned in the present incinerator." So far as the sewage treatment plant is concerned, this recommendation involves the installation of a grinding station over the main sewer at the entrance to the sewage treatment plant grounds and the construction of additional digester capacity. Three additional digesters were recommended. The total cost of the installation is $175,000.

In view of the fact that the Gary work is proceeding under a P.W.A. grant, it was necessary to make an amendatory application action on which is still pending before the Federal Emergency Administration of Public Works.

Not the least among the factors leading to the above recommendation was the value of the additional gas which would be secured from digestion of the garbage solids. It was estimated that this would amount to from $13,000 to $19,500 per year valued in terms of equivalent power otherwise necessarily purchased.

Personnel—The Indiana Sanitary District law wisely sets up an appointive non-political board of engineers for administration. At Gary this board consists of Mr. Ralph Rowley, engineer for the Illinois Steel Company since the inception of Gary, Mr. W. P. Cottingham, City Engineer and for over twenty years connected with that department, and Mr. Boyd E. Phelps, an engineer with a background of heavy construction experience principally in highway work. Such a board combines the board engineering background with the detailed knowledge of the local problem.

The construction work is about one-third finished. The principal construction contracts are being executed by the Permanent Construction Company and Strandberg and Spencer, Inc., of Chicago. Alvord, Burdick and Howson are engineers with Mr. W. W. Mathews as their resident engineer in charge of construction.

DEVELOPMENT OF FLASH DRYING SYSTEM OF SEWAGE SLUDGE DISPOSAL AT THE SANITARY DISTRICT OF CHICAGO*

By Wm. A. Dundas

Engineer of Mechanical Design, The Sanitary District of Chicago

The Engineering Department of The Sanitary District of Chicago has long appreciated the desirability of disposing of sewage sludge and screenings by incineration. Some thought was given to the incineration of sludge as far back as 1914 in connection with experimental studies for treatment of packing house wastes. B.t.u. analyses were made of the screenings, and various sludges from different methods of treatment were investigated experimentally. Owing to the unusually high B.t.u. content of most of these materials the possibility of disposal of sludge by incineration was mentioned in the first report on Industrial Wastes from the Stockyards and Packingtown, dated October 15, 1914.

When construction of the North Side Works was started in 1923, it was intended to dispose of waste sludge from the North Side Works, at least temporarily, by dumping on unused land along the right-of-way of the Main Channel and lagooning. As a result of experimental work done at the Calumet Treatment Works, it was later found that activated sludge could be successfully digested in Imhoff tanks along with fresh sewage solids.

While it was found possible to digest mixtures of fresh and activated sludge in this manner, the high moisture content of the digesting mixture indicated that a very large volume of tankage would be required for the District's various projects. In addition, drying of the large volume of digested sludge on underdrained sand beds would require very large areas, and the use of the beds would be limited to the warmer months of the year. The need for a more compact and self-contained method of sludge disposal, which could be operated continuously throughout the year and dispose of the sludge as fast as produced, was becoming increasingly evident.

In 1931, as the most practical solution, a study of mechanical dewatering, heat drying and incineration was intensively undertaken. Preliminary studies with a small furnace indicated the desirability of constructing a full scale experimental sludge dewatering and incineration plant at the West Side Sewage Treatment Works, with a capacity for handling 20 tons of dry solids per day. This test plant was operated from August, 1932 to May, 1933.

The equipment consisted of a rotary vacuum filter, with 570 sq. ft. of filter area, a rotary dryer 8 ft. in diameter by 70 ft. in length, with stoker fired incineration furnace, conveying and weighing equipment and sludge pumping and conditioning equipment. A vapor condenser

* Presented at the Twelfth Annual Meeting of the Central States Sewage Works Association, Chicago, Illinois, October 12, 1939.

and scrubbing equipment was provided through which passed all vapors and gases from the dryer, together with the products of combustion from the furnace. The incineration furnace was equipped with a reciprocating grate stoker having 80 sq. ft. of grate area. The dried sludge, produced by the dryer, was burned on the stoker. Coal was used when necessary for maintenance of a heat balance.

This experimental plant operated on activated sludge, mixtures containing various percentages of raw settled solids and activated sludge and also on Imhoff tank digested sludge. Nine months operation of this plant verified many fundamentals on the problem of mechanical dewatering, heat drying and combustion.

The experience with the rotary dryer plant established the importance of certain principles and factors necessary for the economical and efficient drying of sewage sludge in a manner free from odor nuisances, to prepare a product suitable to burn or act as a fertilizer. Briefly these are:

1. Maximum surface exposure.
2. Thorough agitation of the wet material.
3. Drying potential of gas.
4. Velocity of drying gas.
5. Responsive and flexible temperature control.
6. Deodorization of gases and vapors vented from the drying operation.

All drying operations utilize the first four of these principles in some form in a more or less efficient manner.

Maximum Surface Exposure

The creation of surface is obtained in various ways, such as spreading on flat surfaces with agitation by plowing, cascading as in rotary dryers or by violent agitation of the material. Greater surface is obtained by recirculating a portion of previously dried material and thoroughly mixing with the wet feed. This practice has been common in drying operations with wet material for over 25 years. It was used by the Sanitary District in drying activated sludge at the Des Plaines River and Calumet Works in 1923, and by the Milwaukee Sewerage Commission later on a much larger scale. Mixing previously dried material with the wet feed in the case of sewage sludge is advantageous also in surfacing wet material with a dry coating, thus preventing sticking on hot surfaces and formation of large balls.

With maximum surface exposure, the time required for moisture diffusion from the material particles to the surface is reduced to a minimum. Further, the maximum exposure of surface means maximum exposure of moisture and, consequently, faster drying, since the rate of drying is directly proportional to the surface exposed, as well as to the temperature differential between the drying medium and material. If a spherical particle ½ inch in diameter is broken up to pass through a 50-mesh screen, the area exposed is 25 times the surface of the original particle

Agitation of the Wet Material

If wet material is agitated and disintegrated to increase surface exposure in a gas drying medium, a violent turbulence is set up between the material and the drying medium. The film of moisture on the particles tends to insulate each particle from the heat of the drying medium. These films are rapidly removed with an increased rate of heat transfer. If the moisture diffuses through the material at a rate slower than the drying medium can carry it away, case hardening of the material takes place. The surface of the material is scorched. In drying sewage sludge this encourages the production of odors and the loss of volatile constituents. If such conditions prevail, the dried material is discharged in lumps with wet centers encased in a hard outer shell.

A condition of maximum surface exposure with violent agitation in the presence of a gas drying medium will disturb the equilibrium between the moisture in the material and its partial pressure in the gas surrounding the material. By greatly increasing the temperature of the gas above that of the moisture in the material, a high differential of vapor pressure is effected. This condition also furnishes the necessary latent heat of vaporization to the moisture on the surface as fast as the film is broken and the vapor carried away. Further, when the temperature of the surface moisture is increased beyond the boiling point, such moisture will exert a force tending to vaporize it into the gas.

Temperatures ranging between 1000° and 1300° F. also result in greater drying capacity per unit volume of drying apparatus. Such temperatures are referred to herein as "high temperatures."

Velocity of Drying Gas

The effects of gas velocity in any drying process should be carefully evaluated. Where the material is in large lumps, high gas velocity is ineffective inasmuch as the major resistance to evaporation results from the high resistance to the diffusion of the moisture from the interior of the material to the surface.

The effect of air currents at various velocities is well known in producing varying rates of evaporation from wetted surfaces and large bodies of water. At a velocity of 3,000 ft. per min. the rate of evaporation is twice and at 4,000 ft. per min., three times as great as at a velocity of 1,000 ft. per minute.

Rapid evaporation of moisture from a wet surface has a pronounced cooling effect on the temperature of the material. This principle is of great value in the drying of sludge inasmuch as the tendency to cool the material retards scorching, and scorching tends to produce odors. However, odors in the heat drying of sludge may arise not only from overheating and scorching of the main body of material, but also from the moisture, which carries considerable volatile organic material in solution. Under normal barometric conditions, the boiling point of water is 212 degrees Fahrenheit, but in high temperature drying the

organic material carried in solution may eventually reach or approach the temperature of the gaseous drying medium. A large percentage of the residue left after evaporation of the solution will be carried along in the gas stream in a vaporous and solid state at a temperature approximating that of the gas stream.

Perhaps the simplest method of breaking down fatty emulsions is by the application of heat. In sewage these emulsions usually exist in a more or less rancid state and with a slight application of heat they produce offensive odors. Even if the main body of material is kept relatively cool in drying sludge, the production of objectionable odors will not be prevented. Therefore all gases and vapors vented from any heat drying of sludge should be treated to destroy odorous compounds.

Responsive and Flexible Temperature Control

In operating the rotary dryer, control proved very difficult when the source of heat for the drying operation came from the incineration of the dried sludge.

A sludge of high volatile content, with 5 to 10 per cent moisture propagates flame with a very rapid heat release, with a flame resembling a gas flame. Burning on a grate thus is difficult and is further complicated by the high ash content, particularly when the products of combustion pass directly into the dryer from the furnace. The combustible in the sludge is consumed very quickly, leaving a heavy ash deposit on the grate, which causes short circulating of the air supply. The ash being relatively light offers only a slight resistance to the passage of air. This condition results in a deficiency of primary air to support ignition of the incoming dried sludge where the fuel bed is dense and affects the distribution of secondary air to complete combustion. Ultimately a drop in furnace temperatures results, which in turn affects the drying operation due to lower temperature gas entering the dryer. The detention period of the wet sludge in the dryer was approximately 45 minutes. Thus many changes could take place without the operator knowing until 45 minutes later.

When sludge appeared at the discharge end of the dryer in an under-dried condition, the operator attempted to correct the condition by feeding more coal to the furnace. This resulted in a rise in gas temperature to the dryer. Again the operator had no means of knowing what was taking place for another 45 minutes unless in the meantime the material became over-dried and ignited within the dryer. When this would occur it was necessary to reduce the furnace temperature as quickly as possible, which was difficult with 80 sq. ft. of incandescent fuel bed and its residual heat. Usually these fires were of short duration, but on many occasions they were not brought under control until the entire contents of the dryer were consumed.

The low fusion point of the sludge ash, 1700 to 1900 degrees Fahrenheit, also has a vital bearing on furnace operation. The fusion point of coal ash approximately 2000° to 2200° Fahrenheit decreased when

both fuels were mixed, the combination having a fusion temperature between 1800 and 1900° F. With this fusion temperature, slagging in the furnace occurred rapidly, with heat releases around 25,000 B.t.u. per cubic foot per hour or over. Molten slag ran into the air spaces between the grates and solidified, causing damage to the stoker and choking of the air supply. This presented a difficult problem of ash handling.

These tests demonstrated the necessity for quick drying without bulk storage of solids in the system, and separation of the drying operation from the combustion; inasmuch as each is separate and distinct from the other. By separating both operations, responsive and flexible control could be obtained.

Deodorization of Gases and Vapors

When sewage sludge and similar materials are dried with heat, odors are produced, which are traceable to a variety of material.

In the rotary dryer plant, all gases passed through a vapor condenser and scrubber in an attempt to remove the odors from the gases vented from the dryer. This proved ineffective, and expensive in operation and maintenance. All the metallic parts were severely attacked by sulphurous acid which formed when the vapors reached the dew point. The interior surfaces were found to be coated with a highly corrosive tarry compound with a very offensive odor. This substance when heated in a retort at first gave off a white vapor followed by a very offensive brown gas, which ignited readily. The gases of combustion from this brown gas had an odor similar to those resulting from the combustion of smokeless powder. The vapor condenser functioned solely as a wet dust collector.

The successful elimination of odors thus proved to be a combustion problem. All the vented gases from the drying of sludge must be passed through the combustion chamber of the furnace at as high a temperature as possible, above 1100° F., in the presence of sufficient oxygen to assure complete combustion of the offending compounds.

This requires the heating of all vapors and gases to furnace temperature, and unless recovery of heat in the exit gases is made, the operation from a thermal standpoint is inefficient and expensive. The stack temperature of a furnace supplying heat for a drying or evaporating process of this nature is a direct measure of the thermal efficiency of the process. Therefore, the heat should be recovered and returned to the process. Figure 1 shows heat requirements with different stack temperatures. Such heat recovery equipment is in daily use in power plants, oil refineries, foundries and other fields operating at temperatures up to 2000° F. With the return of heat recovered, to the drying process, this effective method becomes economical.

Experimental Flash Drying and Incineration Plant

A second experimental drying and incineration plant was designed and constructed to experiment with flash drying of sludge, burning of

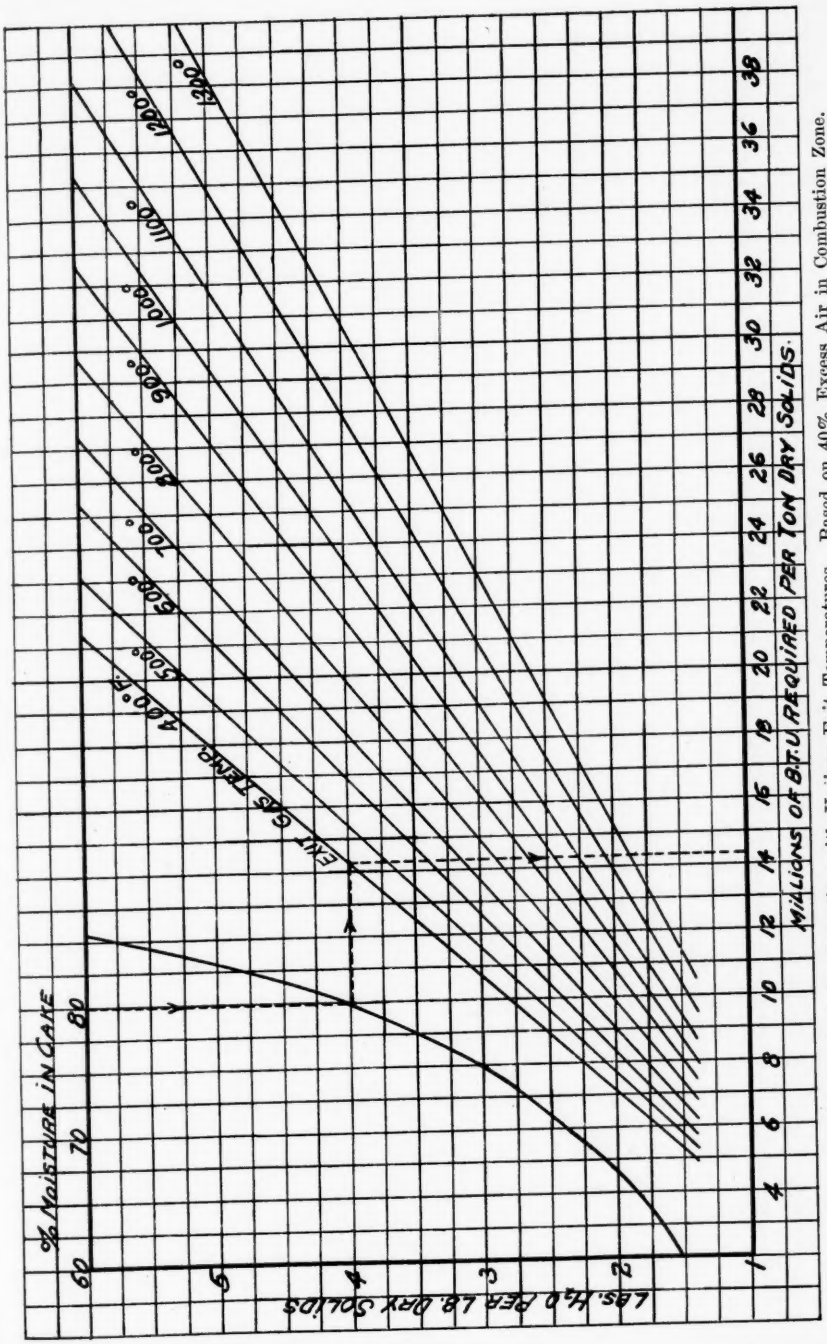


FIG. 1.—Heat Required for Operation with Various Exit Temperatures. Based on 40% Excess Air in Combustion Zone.

the dried sludge in suspension, and deodorization of gases by passing through the combustion zone of the furnace, with heat recovery from the stack gases. The design capacity was based on the disposal of 20 tons of dry solids per 24 hours. The plant was placed in operation in February, 1934.

The equipment consisted of three impact drying mills and one coal mill for firing supplementary fuel. All gases from the drying operation were passed through the combustion zone of the furnace, and along with the products of combustion from the burning of the sludge passed through preheaters before release to the atmosphere. The heat recovered from the furnace exit gases was returned to the drying system and furnace.

While the impact mills performed their function satisfactorily, it developed that the high degree of comminution effected by this type of equipment was not necessary for drying and burning of sludge. Therefore a cage drying mill to evaporate 5,000 pounds of water was installed which when placed under test over an 8-hour period reached an evaporation rate of 7,200 pounds of water per hour. The power consumption of the cage mill was found to be approximately one-third that of the impact mills.

With the installation of the cage dryer the drying system was changed to permit operation on a vapor cycle instead of an air cycle as originally used. This provided an inert drying medium with a specific heat approximately twice that of air.

These tests demonstrated on a large scale that the flash drying of sludge utilized all the fundamentals of successful drying at an economical cost. The desirability of separating the drying and combustion operations was definitely proven. Likewise, separate drying and burning was found to lend itself to extremely accurate and flexible control.

Burning in suspension with its flexibility of control also proved to be economical and desirable. The dried material was thoroughly sterilized in passage through the drying system, which passage occurred in a matter of seconds, and none of the properties desirable in fertilizer were affected.

The passage of all gases and vapors through the high furnace temperature in the presence of excess air was likewise found to eliminate all objectionable odors.

The operation of this plant was discontinued in August, 1935.

Calumet Sludge Disposal Plant

The Calumet Sewage Treatment Works serves an area of about 95 square miles on the South Side of the City of Chicago. The plant is designed to serve a population of approximately 450,000 with an average daily sewage flow of 136 million gallons by the activated sludge process.

The waste activated sludge is brought to two sludge concentrating and control tanks where it is mixed with fresh solids and grit from the

preliminary settling tanks. Ground screenings are also mixed with the sludge at times The mixture of sludge, ground screenings and grit is dosed with ferric chloride prior to dewatering on the vacuum filters.

The sludge disposal plant is designed to dispose of 40 tons of dried solids per 24 hours either by drying followed by incineration or by drying and diversion of the dried material for fertilizer.

The dewatering equipment consists of four rotary vacuum filters each of 570 sq. ft. of filtering area. Each filter has a capacity of approximately 20 tons of dry solids per day, when delivering cake containing approximately 80 per cent moisture.

The drying equipment consists of three flash-type units with independent furnaces and high temperature preheaters. Each dryer and furnace has a capacity for handling 20 tons of dry solids per day when supplied with filter cake containing 80 per cent moisture. At present two units handle the plant solids load leaving one unit as a spare. Space is provided in the building to install future equipment for the ultimate plant capacity of 70 tons of dry solids per day.

The conveying equipment originally installed in this plant was planned from the results of the experimental plants. Belt conveyors moved the wet cake from the filters to a central mixing unit, were the wet cake was mixed with previously dried sludge The mixture of wet cake and dried sludge, containing from 40 to 50 per cent moisture, was picked up by an enclosed drag conveyor which elevated the material vertically approximately 30 feet to a horizontal drag conveyor for distribution to the three individual drying systems.

The dried sludge from the individual drying units was collected by a common screw conveyor and brought to a common surge bin from which a portion of sludge was withdrawn for mixing with the wet cake; the remainder was elevated by an enclosed drag conveyor to a common firing bin, or diverted to a fertilizer storage bin. At first powdered coal was used as supplementary fuel, the powdered coal being transported by screw conveyors from a central preparation plant to the individual burners. Cottrell precitipators were provided for removal of fine ash carried in the stack gases. A hydraulic system of ash disposal was installed on each furnace, with disposal by pumping to a lagoon.

The plant went into operation in July, 1936, and much difficulty was encountered with the conveying system and methods of feeding dried sludge and powdered coal to the burners. The drying systems functioned successfully, but the bottle neck in the conveying systems made it impossible to operate the dryers to their full capacity.

The main difficulties encountered with the conveying system resulted from severe wear and plugging, together with a dust nuisance resulting from attempts to convey dried material in so-called totally enclosed conveyors. The centralized mixing unit likewise caused considerable dust nuisance inasmuch as it was impossible to provide a dust tight seal at the wet cake entrance.

Screw conveyors as a means for feeding dried sludge and powdered coal to the burners were unsatisfactory, inasmuch as the pulsating dis-

charge of the screws caused feeding in separate batches, which resulted in improper mixing of fuel and primary air. This resulted in poor combustion and a high carry-over of unburned fuel in the stack gases, which on one occasion accumulated to such an extent in one of the preheaters as to cause destruction of the heater by combustion of the material in the presence of excess air discharged from the furnace. This was not in any way chargeable to defects in design or construction of the heater nor its ability to withstand the temperature under which it was designed to operate, which was 1800° F. The temperature rose to 2400° F., thus causing fusion. The complete material handling system was therefore remodelled by lowering the drying mills to the basement

TABLE I.—*The Sanitary District of Chicago Calumet Sewage Treatment Works Operating Record Incineration Plant*

Average Daily; Maximum and Minimum Day
August, 1939

Data	Average	Maximum	Minimum
CONDITIONING AND DEWATERING:			
Raw Sludge			
Dry Solids, per cent	2.87	4.26	2.43
Volatile, per cent	55.6	58.8	51.4
Conditioned Sludge, pH	4.5	4.7	4.0
Filter Cake			
Wet, tons	153.8	191.9	84.4
Dry Solids, per cent	17.5	24.5	14.6
tons	26.8	34.7	15.5
Ferric Chloride, per cent	7.1	10.6	4.6
Filtrate			
pH	4.5	5.5	4.0
Suspended Solids, P.P.M.	102	528	52
Iron, P.P.M.	433	800	100
DRYING:			
Dried Sludge			
Burned, tons	1.3	8.0	0.0
Fertilizer, tons	25.5	34.7	15.5
Dryer Feed Dry Solids, per cent	76.0	82.2	68.7
Dried Product			
Dry Solids	93.6	96.1	90.1
Volatile	53.6	56.7	48.8
Nitrogen	4.14	4.78	3.32
INCINERATION:			
Fuel			
Oil, gal.	3,003	4,450	1,597
Sludge, B.t.u.	5,565	5,952	5,217
Total Therms	4,584	6,590	2,360
Water Evaporated, 1000 lb.	254	328	138
B.t.u. per lb. H_2O Evap.	1,805	2,710	1,620
HOURS OF OPERATION:			
Plant (entire)	23	24	15
Thermal Efficiency	62.4	69.6	41.6

floor, approximately 10 ft. below the original operating floor, and equipping each drying system with an individual surge bin, mixer and direct firing fan. Eleven conveyors and one elevator, together with fuel bins and other miscellaneous apparatus, were completely removed.

Because of the relatively small amount of supplementary fuel required to maintain a heat balance, oil was substituted as a supplementary fuel in place of coal.

The mechanical conveying of dried sludge was completely eliminated. All such material was confined in ducts under negative pressure. These alterations provided continuity of service, freedom from dust and odors within the plant and permitted operation of the equipment at full design capacity with a high degree of flexibility and responsive control.

The interruptions in the operation of the Calumet plant were only occasioned in part by defects in methods for transportation of material. Considerable experimental work was carried along as a basis of design for the sludge disposal plant of the Southwest Sewage Treatment Works.

With changed firing conditions slagging of the ash occurred in the furnaces This problem, while troublesome for a short time, proved to be purely a function of furnace temperature and was quickly eliminated by readjustment of the waste vapor and secondary combustion air inlets.

Since the alterations were completed on July 1, 1938 the plant has operated continuously, disposing of the entire waste solid load in an efficient and economical manner, with complete freedom from odors, dust and other nuisances.

Tables I and II show a representative summary of operation for the Calumet Plant.

TABLE II.—*The Sanitary District of Chicago Calumet Sewage Treatment Works Incineration Plant Monthly Operating Record*
August, 1939

Data	
Wet Cake, tons	4,768
Dry Solids, tons	831
Ferric Chloride (dry) tons	57.5
Dry Solids, per cent	7.1
Disposition of Dried Solids	
Burned, tons	39
Fertilizer, tons	792
Fuel Oil Consumed, gallons	93,071
Water Evaporated, 1000 lb.	7,875
Plant Operating Hours	716

SOUTHWEST SLUDGE DISPOSAL AND STEAM GENERATING PLANT

The estimated tributary human population to be handled at the Southwest Sewage Treatment Works by 1940 is 1,277,000, together with

industrial wastes equivalent to a human population of approximately 1,155,000, largely originating in packingtown. The design flow is 400 M.G.D. average, and a maximum of 600 M.G.D.

The equipment includes filters and flash drying equipment capable of processing an average of 375 tons of dry solids per day, approximately one-third of the capacity being chargeable to solids which originate at the North Side Sewage Treatment Works. The processed sludge may be incinerated or diverted for fertilizer.

The drying capacity is divided between four individual units, each served by six filters, each with a filtering area of 570 sq. ft., each dryer unit has normal capacity of 40,000 pounds of water per hour.

Sludge is burned in suspension in a combined water walled furnace and vertical water-tube steam generator. The heat from the combustion of the combined fuels is used to generate steam and supply heat for the flash drying systems. There are four combined steam generator and water walled furnaces arranged to operate in conjunction with an individual drying unit.

Each steam generator has a maximum capacity of 110,000 lb. of steam per hour at 450 lb. pressure gage, and a total steam temperature of 735° F. The steam is used in direct connected turbines to drive the main sewage pumps and blowers and to generate electric power for the operation of electrically driven equipment throughout the entire treatment works, as well as at the West Side Works.

In principle the flash drying system in this plant is identical with that at the Calumet plant. Whatever differences exist are constructional only.

The liquid sludge is pumped up to the top floor of the building where it is dosed with ferric chloride solution, mixed and applied to the vacuum filters. The wet cake drops on to horizontal belt conveyors delivering direct to the mixers, from which the mixed sludge drops by gravity into the drying circuit. The sludge in the drying system is elevated to the cyclone separators while drying in suspension in the vapor stream. When separated it falls by gravity into the fuel and surge bins, from which a portion is diverted for mixing with the wet cake and the surplus passes by gravity into the sludge firing lines or to the fertilizer conveyor. This method of material handling has reduced to a minimum the use of the simplest type of conveying equipment.

Ducts and equipment containing dried sludge, dust and vapors are kept under negative pressure.

Any equipment which operates simultaneously or in series with other equipment, is interlocked electrically and arranged for sequence starting and stopping. Thus failure of one piece of equipment served by another, merely causes the preceding equipment to shut down, thus avoiding possible damage and confusion in operation. Sequence starting and stopping likewise prevents starting and stopping difficulties, as equipment can only be placed in operation or stopped in the proper order.

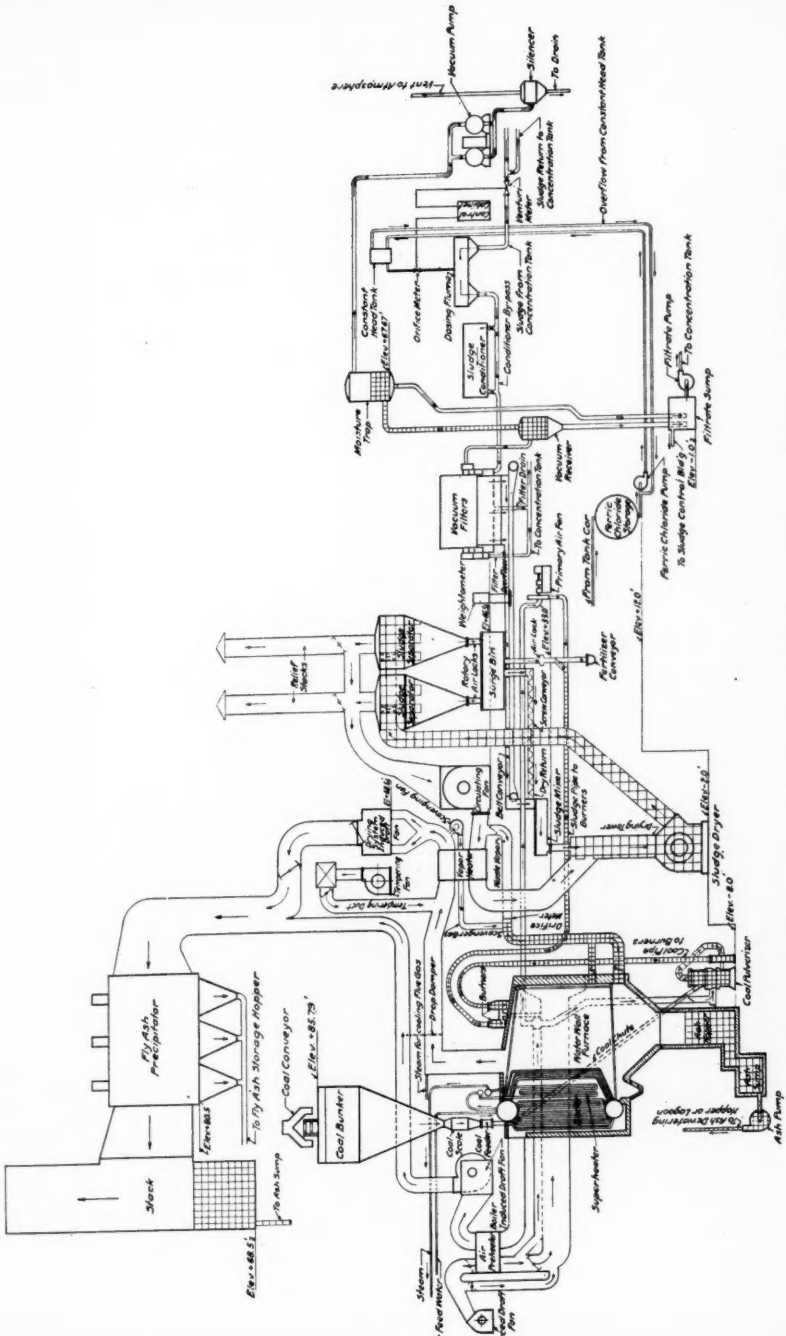


FIG. 2.—The Sanitary District of Chicago, Southwest Sewage Treatment Works, Sludge Disposal Plant, Flow Diagram.

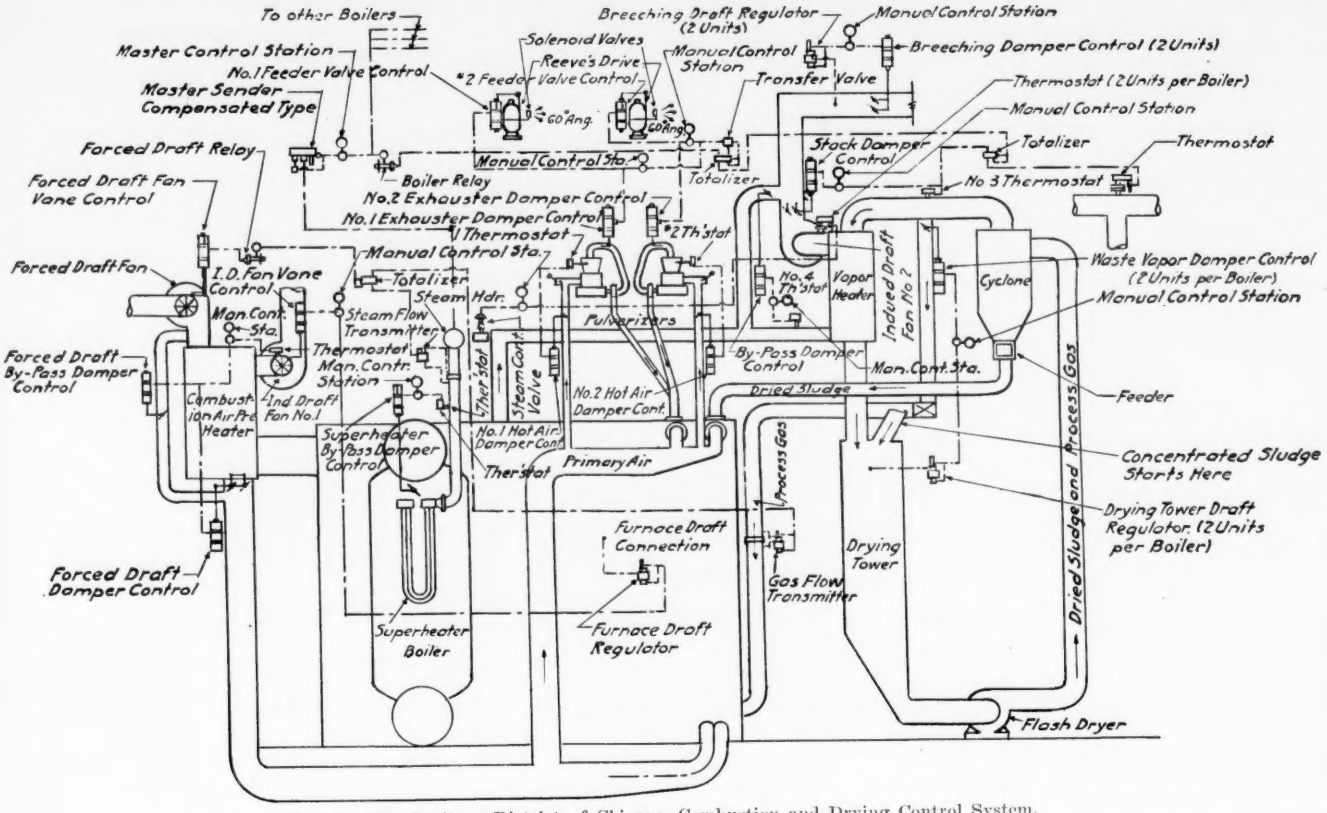


FIG. 3.—The Sanitary District of Chicago, Combustion and Drying Control System.

The control of the drying and combustion operations in general is automatic. Combustion air is controlled by the quantity of heat drawn from the system, this heat being the heat in the steam and in the waste vapor. This controller operates a vortex damper on the boiler forced draft fan and receives its impulses from a steam flow meter and a waste vapor flow meter.

The steam pressure is controlled through a master controller which maintains constant steam pressure by controlling the quantity of coal fired in the individual furnaces Sludge firing is hand controlled. Steam temperatures are controlled by a thermostat which is arranged to operate the superheater by-pass damper.

The total amount of primary air is controlled in relation to the coal feeder. In order to prevent combustion in the coal pulverizers the temperature of the air to the mill is regulated by a recording thermostatic controller, which operates a damper in the hot air supply to the coal mill. A balanced tempering air damper permits room air to enter the system as the hot air damper is throttled. Overloading of the mill motor is prevented by relays in the motor circuit arranged to cut out the coal feeder when the mill motor current exceeds 10 per cent over full load current.

The primary air for the sludge is manually controlled and is more dependent upon the quantity required for transport air than the correct amount for primary air. Secondary and tertiary air for both sludge and coal is controlled manually.

Sludge drying is accomplished by circulating a constant quantity of highly heated vapor in the drying system, the temperature differential of the vapor between inlet and outlet varying with the drying load. Temperature control is accomplished by a thermostat in the sludge separator arranged to control the position of the dryer induced draft fan damper. This maintains a constant separator temperature and varies the temperature of the vapor to the drying tower by varying the quantity of hot gas drawn through the vapor heaters.

The temperature of gases entering the vapor heaters is maintained at 1500° F. by admitting room air to mix with the hot gas from the furnace. A control thermostat set in the gas duct just before the heater, operates a damper in the cold air tempering duct.

Pressure in the drying tower is controlled by a draft controller which operates the damper in the waste vapor duct between the circulating fan and the furnace.

Figure 2 is a complete flow diagram for the sludge disposal plant.

Figure 3 is a schematic diagram of the combusion and drying control systems.

OPERATING PROBLEMS IN STARTING THE SOUTHWEST PLANT OF THE SANITARY DISTRICT OF CHICAGO*

By A. H. Goodman

Engineer of Plant Operation

I will outline briefly the organization of the supervisory forces that are responsible for the operation of the combined West-Southwest Plants. At the West Side Works, B. A. Scheidt, Assistant Civil Engineer, is in direct charge of sewage treatment and at the Southwest, C. T. Mickle, Assistant Civil Engineer, has similar responsibility. G. G. Poindexter, Senior Sanitary Chemist, directs the chemical work for the combined plants, and E. Hurwitz, Principal Sanitary Chemist, supervises the laboratory work for the Southwest Plant in addition to his other duties as Assistant to Dr. Mohlman in the Main Laboratory. R. C. Hageman, Senior Mechanical Engineer, is in immediate charge of all mechanical operation and maintenance work for both West and Southwest. L. M. Keoughan is the Electrical Engineer and J. J. Schneider the Chief Operating Engineer for the combined plants. I want to take this opportunity to thank these men and the junior engineers working with them, as well as all other employees, for the splendid co-operation which has made possible what success we may have had in getting this project into operation.

It is rather thrilling to visualize the treatment of 500 to 600 m.g.d. of sewage and approximately 600 dry tons of sludge per day. The problems have been many and will be with us for months to come. The various experiences we have had in operation up to date will be discussed by Messrs. Mickle, Poindexter, and Hageman.

TREATMENT PROBLEMS

By C. T. Mickle

Asst. Civil Engineer

The West-Southwest Plant of the Sanitary District of Chicago, although operating as a single plant under one head, is made up of two complete units. The intercepting sewers that bring sewage to the plant are cross connected, making it possible to pump sewage to both units from either interceptor. This made it possible to start operation at the Southwest plant with sewage from the West Side Interceptor. The flow through this cross-connection is controlled by two motor operated sluice gates each 72 in. by 96 in.

With a tributary area of 40 sq. miles at the West Side, and 192 sq. miles at the Southwest Plant, it is estimated that the total tributary

* Presented at the Twelfth Annual Convention of the Central States Sewage Works Association, Chicago, Ill., October 13, 1939.

population equivalent to the combined plants in 1940 will be 4,273,000. In addition, the sludge from the North Side is being pumped to the Southwest Plant bringing the solids load from a population equivalent of 1,291,000. The total sewage solids to be handled by the combined Plant, will be from a total population equivalent of 5,564,000. It is estimated that this solids load will be approximately 600 tons of dry solids per day, of which 375 tons per day will be handled by the Southwest Plant.

Located ahead of the sewage pumps are six coarse bar screens with 2-in. clear openings, through which sewage entering this plant must pass. Motor drives for these mechanically cleaned screens are located above the high water line. Coarse screenings are dropped by the cleaners into a steel trough, from which, using plant effluent, they are sluiced into a skip hoist. This hoist drops them into a railroad dump car to be disposed of on Sanitary District property some distance west of the plant.

Before the sewage pumps could be started, temporary pumps were used to remove all water from the interceptor and pump suction pits, in order that debris accumulating after construction "clean ups" might be removed. Coarse screens and screen cleaning mechanisms were adjusted for operation at the same time.

Four main sewage pumps, each with 300 c.f.s. capacity at 54 ft. total dynamic head, discharge into a common chamber, from which the sewage flows through separate influent channels to the two batteries of preliminary tanks.

Overflow siphons at the pump discharge chamber make it possible to by-pass sewage ahead of the preliminary tanks and also prevent accidental flooding over channel walls. Also at the pump discharge chamber is the first of three possible sources of condenser water.

The pump discharge chamber and the influent channels to the preliminary tanks are aerated with diffused air to keep solids in suspension and as an aid in grease removal. These channels are approximately 800 ft. long. At a flow of 400 m.g.d. they provide a detention period varying from 7 minutes at the first tank influent to 17 minutes at the last influent weir.

Preparatory work here consisted of setting and testing of air diffuser plates and miscellaneous clean up. Before setting diffuser plates, all air mains were "blown out," using air from the main steam turbine driven blowers, which were operated without condenser water.

There are six tanks 101 ft. by 103 ft. 6 in. in each of the two batteries of preliminary tanks. Every tank is divided into six bays. Each bay is equipped with a straight-line type of conveyor which moves sludge to the influent end of the tank, where two cross conveyors move it to a centrally located sump. Sludge is removed from these sumps by air lifts which raise it approximately one foot above the water surface of the tanks. It flows into sludge discharge boxes and then by gravity through pine lines to the concentration tanks. One 8-in. air lift is provided for each tank. To date, our preliminary sludge has amounted

to about 2.3 per cent of the total sewage pumped and has contained an average of 0.3 per cent solids.

Conveyor flights, which move sludge across the bottom of the tank, ascend and return along the surface, carrying scum to skimmers at the effluent end. This skimmer mechanism consists of a traveling car and baffle which, when propelled back and forth across the end of the tank by an endless chain, pushes scum to the corners of the tank where an arm extending ahead of the car trips a tilting bucket. The tilting of the buckets allows scum to be drawn off the surface of the tank along with sufficient sewage to flush it through the pipe discharge lines. At present scum is being discharged into the outfall. However, a separate incinerator for scum and screenings is contemplated.

Preliminary tank effluent flows through twin conduits to the gate house where the flow is divided and measured by venturi meters. Four sluice gates 84 in. by 120 in. control the flow to the two batteries of aeration tanks. Ahead of these sluice gates, an overflow siphon is located so that preliminary effluent may be bypassed to the plant outfall. Also located ahead of the gate house is the second condenser water take-off. This makes it possible to use preliminary effluent for condenser water. The four 114 in. by 62 in. venturi meters at the gate house are equipped with indicating, recording, and integrating mechanisms.

With equipment up to and including the gate house ready for operation, the first sewage was turned into the Southwest Interceptor from the West Side Interceptor, and pumped into the plant on May 23, 1939. It was given preliminary treatment with a portion of the preliminary effluent being used as condenser water and the remainder by-passed to the outfall. Until the drying system was ready for operation, sludge was routed to the concentration tanks through one of the 20 in. pipe lines and by-passed to the outfall. This first step, although keeping little or no solids from reaching the Drainage Canal, was a start toward routine operation and complete treatment.

Sewage on its way from the gate house to each of the "A" and "B" aeration and final tank batteries passed through a mixing channel 454 ft. long, where return sludge is added and thoroughly mixed by diffused air. This mixed liquor then passes into the aeration tank influent channel which is 1,088 ft. long. Detention periods in the mixing channel and to the various feeds from the influent channel vary from 6 minutes to 46 minutes at a 240 m.g.d. flow of mixed liquor.

The feed to individual spiral flow type aeration tanks is controlled by two 42 in. by 42 in. sluice gates each equipped for electrical operation by a portable electric motor and speed reducer. There are eight aeration tanks 434 ft. long by 136 ft. wide (center to center of outside walls) in a battery. Each tank is divided into four passes so that mixed liquor travels 1,736 ft. in the aeration tank. Both the influent gates and effluent weirs are at the operating gallery end of the tanks. Air is supplied by two continuous rows of diffuser plates the entire length of each bay. Air to diffuser plates in adjoining bays is fed through common pipe lines controlled by valves in the operating gal-

leries and measured by venturi meters equipped with manometers. This makes it possible to use a higher air rate in the first two bays of any tank than is used in the last two. Additional valves are provided at each branch feeding the diffuser plates.

Even with this plan for complete air control, difficulty has been experienced in attempting to secure uniform air distribution. With the plant operating at a uniform flow, sewage load conditions have varied throughout the day so that changes in air rates become necessary. Any such air rate changes make almost unbelievable changes in air distribution conditions. This has necessitated frequent adjustment of the individual plate container valves, and at the lower air rates, operating with one row of plates cut out of service.

Aeration tanks are arranged in pairs, back to back, so that effluent weirs are at the end of adjacent passes on opposite sides of a common wall. The aerated mixed liquor flows over these effluent weirs, and crosses under the operating gallery where it is measured by venturi meters. Downstream from these meters, the effluent from each pair of aeration tanks joins in a common conduit and rises into a channel from which the feed for four final settling tanks is taken. A mixed liquor channel running parallel to the operating gallery connects the various final tank feed channels so that a balanced flow can be obtained even though individual tanks are shut down for repairs.

There are sixteen final tanks per battery, each 126 ft. in diameter. They are of the center feed, radial flow type, equipped with center drive clarifier mechanisms. The bottoms of these tanks have a 1-in. per ft. pitch toward the center. The settling rate, with sixteen tanks in service, is 1,200 gallons per sq. ft. per day of mixed liquor at 200 m.g.d. sewage flow and 20 per cent return sludge. We have been operating Battery "A" final tanks at a settling rate of approximately 1,400 gal. per sq. ft. per day and getting fairly good results. However, we hope to be able to improve our effluent from these tanks when operating at this rate.

The mixed liquor entering the final tanks through the center feed pipe is carried by its velocity to the water surface, where it spreads radially to the circular baffle which forms the center well. Here it apparently flows straight down along the baffle and continues to the bottom of the tank, then flows outward until diverted upward by the tank wall. The upward velocity at the outer walls is sufficient to lift sludge particles to a level where they are carried over the effluent weirs, but the parts per million of suspended solids in the final effluent have not been greatly increased. Observation of the tanks in operation has led us to believe that if these currents could be controlled a better final effluent would be obtained.

One final settling tank has been equipped with a circular weir trough about 15 ft. inside the regular weir and the outside weir is blocked off. This draws effluent from the clear area out and away from the tank wall. So far this tank has given the best effluents.

In a second tank, slots have been cut in the steel center well baffle.

There was very little or no flow through these slots until a horizontal baffle was added in the center diffuser casting. With this in place, the entering flow is spread radially, striking the circular center well baffle before reaching the waters surface. This forces some flow through the slots but does not reduce the velocities enough to do much if any good.

A horizontal baffle large enough to extend about 18 in. outside the center well has been built around the center feed pipe in a third tank. In this way it was hoped to establish flow strata in the tank with a dead area below, through which sludge could settle undisturbed. No results of the effects of this arrangement are available as yet. However, the appearance of the effluent is not pleasing.

Sludge level indicators have been installed in all final settling tanks. These indicators consist of four 1½ in. air lifts. The inlets to the four lifts are at 2.00, 3.75, 5.75 and 8.00 ft. above the tank bottom at the outside wall. The lifts all discharge into a common box.

Final tank mechanisms are equipped with plows mounted on four radial arms which sweep the sludge to the center of the tanks, where it is drawn off through pipes leading to the operating galleries. Here, two 16 in. air lifts for each tank discharge it into a common aerated return sludge channel. Two waste sludge lines, one 12 in. and one 16 in., take off at a point downstream from the last discharge into this channel. The waste sludge and return sludge lines then run parallel through a sludge meter vault, which contains venturi meters for measuring both return and waste sludge. Also in this vault are electrically operated valves for controlling the amount of waste. From this point, waste sludge flows by gravity to the sludge control building.

The total amount of air being used in all aerated channels and air lifts mentioned amounts to approximately 0.13 cu. ft. per gallon of sewage. Of this about 0.04 is used in the preliminary tank channels and preliminary sludge lifts, 0.07 in the aeration and final tank channels and 0.02 in the return sludge air lifts.

The third possible source of condenser water is from Battery A final effluent conduit. Final effluent is ordinarily used but preliminary effluent and raw sewage are available for emergency use.

Southwest preliminary sludge, Southwest waste activated sludge, and North Side sludge are mixed in an aerated mixing chamber at the sludge control building. The sludge mixture is then passed through mechanically cleaned bar screens with ½ in. clear openings, then flows through an aerated influent channel to the concentration tanks. In each of the six tanks, each 46 ft. 9 in. wide and 70 ft. long, sludge is moved to sumps by conveyer equipment similar to that used in the preliminary tanks. The original installation anticipated pumping direct from each concentration tank sump to the sludge disposal building. However, by making a very minor change in piping we are now able to run Tanks 1 to 4 inclusive in series with Tanks 5 and 6. Thus we are able to use Tanks 5 and 6 as storage tanks from which sludge can be pumped to the disposal building. This avoids danger of quick changes of density in the sludge going to the filters. Some additional concentration has

been obtained in Tanks 5 and 6 after settling in Tanks 1 to 4. This may be due to the additional settling time or may be entirely due to the higher sludge level carried in Tanks 5 and 6.

Considerable time and thought were given to the preparation of blank forms for daily operation records. Blanks were made for recording hourly readings in the various operating galleries. Spaces were provided to collect information necessary in compiling permanent plant records. Blanks for readings, or notes of periodic inspections, such as checking of samplers, were included to insure that all controls and equipment received the proper attention.

As previously stated, preliminary treatment was started May 23, 1939. June 9th, two Battery A aeration and four final tanks were placed in service, and as setting of diffuser plates progressed other tanks were added. July 5th, concentration of sludge was begun. August 1st, a mixture of Southwest preliminary and North Side sludge was filtered. August 8th, the first sludge was dried and burned in the incinerator. September 6th, four Battery B aeration tanks and all final tanks were put in service. Thus, step by step, practically the entire plant has been put into operation.

CHEMICAL CONTROL

By G. G. Poindexter

Senior Sanitary Chemist

The findings of research workers who have investigated the various phases of sewage treatment, particularly in the mechanism and characteristics of the activated sludge floc, have given the operating chemist not only a greater insight of the job to be done, but also have set standards of accomplishment in sewage treatment. It is the purpose of this article to review briefly the application of some of these principles and to indicate to some extent their effectiveness in the control of a large activated sludge plant. It must be recognized that any conclusions drawn at this time are highly tentative, with so short a period of operation on which to base experience.

Control of the treatment process at the Southwest Treatment Works of the Sanitary District of Chicago is facilitated by certain conditions not encountered in most plants. In many cases the operators must meet not only changes in sewage strength, but changes in volume of flow, at the same time. At the Southwest Plant, because of the coordination of its operation with that of the West Side Treatment Works, it is possible to take through the plant a constant flow, the remainder passing through the West Side. This allows the operator to focus attention on the variations of sewage strength only. Furthermore the influent is comparatively weak, and its variation throughout the day is not wide. Hourly samples of dry weather sewage at the West Side showed a B.O.D. range in 24 hours of from 172 p.p.m. to 39 p.p.m., and a suspended solids range of from 299 p.p.m. to 58 p.p.m.

While similar investigation at the Southwest Plant will not be of value until the entire area is connected to the interceptor, it is believed that variations in sewage strength will not constitute a major problem in plant operation.

The purification process may be divided into three main divisions: (1) preliminary sedimentation and scum removal, (2) aeration of the settled sewage along with settling of the aerated mixture, and (3) disposal of the sludge solids. Since at this plant the operation of the primary settling tanks promises a minimum of difficulty (disposal of skimmings to depend on experience in the near future), and since dewatering and incineration of sludge is largely a mechanical process, the plant chemist can devote most of his efforts to control of the activated sludge process.

The first two aeration tanks, along with six final settling tanks, were placed in operation June 9, using sewage diverted from the West Side interceptor. Rainy weather combined with a long period of primary sedimentation produced a very dilute aeration tank influent. The aeration period was 3.7 hours, the return sludge 40 per cent, and the air 0.7 cu. ft. per gallon of sewage. Additional tanks were placed in service as they were ready, the entire eight tanks of the first battery being in operation by June 27, with a sewage flow of 200 m.g.d. Twenty-eight days after the first sewage was taken the suspended solids of the mixed liquor reached 1,900 p.p.m. Air rates were reduced to meet the actual demand, and the return sludge volume was adjusted to maintain the suspended solids in the mixed liquor between 1,500 and 2,000 p.p.m. Air used in aeration tanks averaged .25 cu. ft. per gallon of sewage treated for the month of July (first complete month of operation). The suspended solids in the mixed liquor averaged 1,945 p.p.m. for the same period. The return sludge volume averaged 22 per cent of the sewage flow, with a maximum of 30 and a minimum of 13 per cent.

Of prime importance in controlling the aeration process is the determination of dissolved oxygen in the aeration mixture. These tests are made every four hours, or more often, according to conditions, in the operating galleries by the gallery operators. Results are reported immediately to the engineer on duty. Samples are taken at six points in one of the middle tanks of the battery, from the influent to the effluent end. Ten c.c. of 5 per cent copper sulfate solution is added to each quart sampling bottle to stop bacterial action. By the time the samples reach the laboratory desk in the operating gallery the solids have settled sufficiently to permit siphoning of a sample for dosing. A modification of the Winkler method is used. The Winkler method for determination of dissolved oxygen is susceptible to error in the presence of nitrite. The Rideal-Stewart modification corrects this error but complicates the procedure. Alsterberg (1925)[1] added a small amount of sodium azide to the alkaline potassium iodide to eliminate the nitrite. More recently Brandt,[2] Ruchhoft,[3] Barnett and Hurwitz [4] have worked on similar applications of this substance. Hurwitz found that the addition of 1 per cent sodium azide, using Alsterberg's original method,

was effective in removing the nitrite from samples collected at the Southwest Plant. A typical series of such tests, on samples containing an average of 2.6 p.p.m. of nitrite, using the Winkler method alone, the Rideal-Stewart modification, and the Alsterberg modification, gave results of 9.7, 5.8, and 6.0 p.p.m., respectively. Availability of this method has made the difference between success and failure in the determinations of dissolved oxygen by the non-technical members of the operating personnel.

In addition to dissolved oxygen determinations, settling tests are made every four hours on mixed liquor and return sludge. The mixed liquor tests indicate any radical change in the settling characteristics of the sludge, and the average results for the day are used in calculating the sludge index according to the definition of Mohlman,[5] *i.e.* the volume occupied by one gram of sludge solids after 30 minutes settling. The average monthly sludge index to date has varied from 63 for July, to 79 for September, a month marked by negligible rainfall.

The settling tests on return sludge are particularly valuable at this plant, since due to the flow characteristics of the final settling tanks, as described by Mickle, it is necessary to keep the sludge blanket as low as possible. A rapid drop in the settleable solids in the return sludge indicates too high a wasting rate. Presence of sludge in the air-lift operated sludge level indicators, also described by Mickle, shows, on the other hand, too low a return from a particular tank, or, if manifest in a number of tanks, too low a wasting rate.

Two important influences on operation have appeared thus far. The first arose from the use of chlorinated effluent as cooling water in the condensers of the steam-driven units of the pump and blower room. The second was encountered when the Western Avenue sewer, carrying about half the load from the packingtown area, was connected to the Southwest interceptor. They will be discussed in order.

The effluent used for cooling is chlorinated intermittently to prevent slime deposits on the surfaces of the condenser tubes, a residual of 0.35 to 0.5 p.p.m. of chlorine being necessary for that purpose. From May 23 to June 27, primary tank effluent was used for condenser cooling and other purposes where polluted water could be substituted for city water. The chlorine demand, while not constant, was within the capacity of the chlorinator. On June 27, the use of final effluent was started, and almost immediately it was apparent that the maximum capacity of the chlorine equipment was exceeded. During the first several days of operation of the activated sludge unit, high air rates were applied to a weak, rain diluted sewage, resulting in the production of considerable amounts of nitrite. Nitrite and chlorine react immediately, each part of nitrogen as nitrite requiring 2.53 parts of chlorine to satisfy its demand. The maximum nitrite recorded was 5.4 p.p.m. which would require for an estimated flow of 43 m.g.d. through the condensers a dosage rate 2.7 times the capacity of the chlorinator. To correct this condition air rates in the aeration tanks were cut in an attempt to hold the dissolved oxygen content of the aeration mixture

as low as possible consistent with good sludge condition and a final effluent of good quality. Nitrites were reduced to an average of 0.8 p.p.m. for the last five days of July, and an average of 0.48 p.p.m. for the month of August. It was found that with a dissolved oxygen content between 1.0 and 2.0 p.p.m. in the mixed liquor at the end of the tanks, little nitrite was formed. The chlorine dosage rate was reduced to 700 lb. per 24 hours for the condenser water required at the time. It is expected that as the operating personnel gain experience in control of the aeration process, consistently low nitrites may be maintained, so that with maximum use of final effluent for condensing, the present chlorine dosing equipment will prove sufficient, except, perhaps, during a few periods of frequent rainfall, at which times chlorination is least needed.

With a five-hour aeration period the air requirements were so low that settling of sludge solids was feared. To avoid this, on July 12, two aeration tanks were drained, reducing the aeration period to about 3.7 hours, thus increasing the air flow per diffuser plate. Treatment was entirely satisfactory, but uneven distribution of mixed liquor to the final settling tanks resulted. Consequently, on August 14, two additional aeration tanks were drained, and the entire flow of 200 m.g.d. was passed through four tanks, with a detention period of about 2.6 hours. Treatment of similar sewage at the West Side Plant, using Imhoff tank effluent as influent to an experimental activated sludge unit, had given good results at detention periods ranging from 1.25 to 2.0 hours.

Operation on the 2.6 hour detention period continued until September 7, when the Western Avenue sewer was cut in. The effect of this was immediate. In the preliminary tanks greatly increased scum and grease were observed. The activated sludge effluent became dark and murky, and a film of grease appeared over the surface of the final settling tanks. The analysis of the effluent did not change materially except that the organic nitrogen was twice its normal figure. The sludge showed no signs of bulking. The dissolved oxygen in the mixed liquor dropped from between 1.5 and 2.0 p.p.m. to 0.4 to 0.6 p.p.m. at the end of the aeration tanks. On the theory that the plant might adjust itself to the increased load, the sewage flow was cut to 100 m.g.d. with air flow at the maximum capacity of the meters, but improvement, if any, was too slight to measure. Consequently, after four days including the week end, the remaining tanks of the battery were placed in service, restoring the 5 hour aeration period. Two days later the plant was again in normal condition. The change in sewage strength is best reflected by its analysis. For the month of August the B.O.D. average was 60 p.p.m. and the suspended solids 78 p.p.m. For the 24 days of September following the opening of the Western Avenue sewer, the B.O.D. average was 105 p.p.m. and the suspended solids was 131 p.p.m. Air consumption for the two periods averaged .27 cu. ft. and 0.38 cu. ft. per gallon of sewage. While the activated sludge plant is again operating on a 5-hour detention period, the slight additional air requirement appears to have eliminated the objections which led to the

adoption of shorter aeration periods. It is believed that when additional final settling tanks are provided, operation with a 3.5 hour detention period will be possible.

In the sludge disposal system the plant chemist is interested mainly in the sludge fed to the vacuum filters and in its coagulation. The continuous mixing of preliminary tank solids with the activated sludge solids, plus the high percentage of fresh solids received along with the activated sludge from the North Side plant, should produce a readily filtrable sludge, and the two-stage concentration of the mixed sludges in the concentration tanks makes available a sludge of fairly uniform consistency. Automatic measuring equipment is installed ahead of the dosing flumes in the filter room to regulate the apportioning of ferric chloride in any desired ratio to the feed sludge. Centrifuge readings on the feed sludge have proved of value in approximating the solids content of the filter feed at the Calumet Plant, and will be used at the Southwest Plant as soon as installation of the centrifuges is complete. The point of optimum filtration is obtained from a series of Buechner funnel tests, the results being translated into operation in terms of pH. The volume of filtrate caught in an arbitrarily set number of seconds, plus the time of the vacuum break, are used as criteria for plotting a curve. Typical results to date indicate a possible pH range of 3.5 to 4.4. This wide range of filtrability allows the operator considerable leeway, although for the sake of economy the pH is held as nearly as possible to the less acid end of the curve, consistent with actual operating experience.

Evaporated final effluent is used as makeup water to the boilers. The Hall system of water treatment is used, and its application is supervised by a member of the mechanical engineering staff. Samples of boiler water are taken to the laboratory for analysis daily, and samples of makeup water, condensate, and blowdown water are taken occasionally. In this connection, some concern is felt over the possible introduction of ammonia from the final effluent into the steam system, where much copper-bearing metal is used. Studies to determine the effect of the ammonia, and measures necessary for its elimination, are now in progress.

Samples of every stage of treatment are taken throughout the plant, automatic samplers being employed wherever possible. At this time it is too early to judge the success of the sampling procedures, but whenever indicated, alternate hand and automatic samples have been and will be taken.

References

1. G. Alsterberg, "Methods for the Determination of Elementary Oxygen Dissolved in Water in the Presence of Nitrites." *Bioch. Z.*, **159**, 36–37 (1935).
2. H. J. Brandt, "The Determination of Oxygen in Water in the Presence of Nitrite." *Gesundh. Ing.*, **60**, 557–59 (1937).
3. C. C. Ruehhoft, *et al.*, "Determination of Dissolved Oxygen." *J. Ind. & Eng. Chem., Anal. Ed.*, **10**, No. 12 (1938).
4. G. R. Barnett and E. Hurwitz. THIS JOURNAL, **11** (1939).
5. F. W. Mohlman, "The Sludge Index." THIS JOURNAL, **6**, 119 (1934).

MECHANICAL ORGANIZATION

By Roy C. Hageman

Senior Mechanical Engineer

Because of the combining of steam generation with sludge drying, the Southwest Sewage Treatment Works is a very unusual type of plant. It is complex and completely mechanized.

The engineer who is responsible for the management of such a plant is faced with a variety of problems. In addition to the actual physical work of starting, operating and maintaining equipment and processes, there is an imperative need of comprehensive planning of methods and procedure and the selection and training of personnel.

An industrial plant usually begins in a small way and expands as business increases. In this, it differs from a modern sewage works which is built to satisfy immediately the demands of an established community. This at once simplifies and complicates the problem of management. It is simplified because once an orderly procedure is developed there is little need for change in the immediate future. It is complicated because of the vast amount of detail which must be handled during a short period of time.

Description of Sludge Drying and Power Plants

Mr. Mickle, in his paper, has explained the sewage treatment processes at the Southwest Works up to, and including, the concentration tanks. In order to provide a better background for a presentation of the problems involved in placing this sludge disposal system in operation, it may be well to give a very brief description of the sludge disposal and steam power plants.

The sludge drawn from the concentration tanks is pumped up to the main operating floor where it is conditioned with ferric chloride and mechanically dewatered by vacuum filtration to a moisture content of approximately 80 per cent.

The filter cake resulting from vacuum filtration is transported on belt conveyors to the drying plant where the remaining water is evaporated by the application of heat. This is done by the process of flash drying described by Mr. Dundas.

The dry sludge produced may be sold as fertilizer or may be burned in the furnaces as a fuel.

All the fuel, sludge or pulverized coal, is fired in the furnaces in suspension. A part of the heat liberated is drawn from the top of the furnaces and passes to the drying system. The remainder is drawn through the boiler and generates high pressure, superheated steam. The steam is used by the turbines which drive the main sewage pumps, blowers, and generators.

Preliminary Preparation

At the Southwest Works we had ample time to devote to the preliminary phase of the work. In addition, we enjoyed the cooperation

of our various design departments. This resulted in an early opportunity to begin the preliminary planning.

At any sewage or sludge disposal plant, the preliminary preparation may be divided into several parts. These are the selection of engineering personnel, training of operating and maintenance personnel, developing and designing of means for keeping records of all phases of the work, and checking of equipment and plant prior to the beginning of operations.

The staff at the Southwest Works was organized on the basis of the physical layout of the plant. The natural divisions of the mechanical work, with a brief description of each, are as follows:

The Pump and Blower House contains the main sewage pumps, blowers, and electrical generators. These are driven by steam turbines totalling approximately 25,000 horsepower. In addition, auxiliary equipment such as surface condensers, condenser air removal apparatus, condensate pumps, oil pumps, condenser water screens and chlorination equipment are either in the building or adjacent to it. Other equipment also located here includes the boiler feed pumps, service water pumps, evaporators and air compressors.

The Steam Generation and Sludge Drying equipment is located in the sludge disposal building. This equipment consists of boilers and furnaces, flash dryers, and vapor heaters. The evaporating capacity totals approximately 600,000 pounds of water per hour, of which about 440,000 represents steam generation and about 160,000 represents sludge drying. The auxiliaries included consist of controls, coal pulverizers, fans, heat exchangers, sludge mixers, conveyors, and a variety of other apparatus.

The Sludge Conditioning and Dewatering equipment is located in the sludge disposal building. Twenty-four vacuum filters are provided with a total combined capacity of approximately 480 dry tons of sludge per day. The auxiliary equipment consists of vacuum pumps, ferric chloride pumps and controls, and conditioning apparatus. In addition, the mechanical equipment at the concentration tanks such as sludge removal mechanisms, sludge screens and sludge pumps may be considered as auxiliary to the sludge dewatering division.

Coal, Ash, and Ferric Chloride Handling constitute another definite division of the plant. The equipment required consists of locomotives, cars, conveyors, elevators crushers, ash pumps, and vacuum producers. An uninterrupted supply of coal and ferric chloride is essential. It is equally important that the ash resulting from the burning of coal and sludge be removed constantly. From 250 to 550 tons of coal per day will be burned and from 60 to 200 tons of ash must be disposed of, depending upon whether the dry sludge is burned as a fuel or sold as a fertilizer.

Testing and Metering is not a division of the plant in the same sense as are the other sections. Accurate measuring, is, however, of extreme importance in attaining high economy in plant operation. The performance of pumps, blowers, generators, turbines, boilers, and the

sludge disposal process can be most readily checked from day to day through the use of flow meters. It is imperative that the water in and the supply of water to high pressure boilers be constantly tested to prevent the formation of scale, corrosion, and other serious difficulties.

The Organization of Maintenance Work constitutes a very important division. Here the important element is the reviewing of all requests for maintenance, adjustments, alterations in design, or new construction which come from the various divisions in the plant. The purpose of this is to assure that the final authorization of work is written in an accurate and understandable manner so as to facilitate the actual performance. Along with other information, this written authority for doing work includes such matters as the exact location, the nature of the work or results desired, and the code designation which locates the file and the charge for the cost system. The authorizing of work in writing has several advantages. By requiring the anticipation of maintenance needs it enables the master mechanic and foremen to organize the time of their men to the best advantage. It lends itself to the cost analysis of equipment and the use of different materials and supplies. It provides a record for ready reference of inspections as well as repairs, adjustments, changes in design, and new construction by the maintenance forces.

A mechanical engineer is assigned to each of these divisions of the plant to follow the work of maintenance and operation, check the performance of plant and equipment, and investigate various problems as they arise. The organization is very flexible because of the fact that each engineer has had the training and experience to perform the work of every other division.

The Training of Operating and Maintenance Personnel is a very important requirement in the starting of a steam power or sludge drying plant.

The problems of maintenance can be simplified greatly if competent and trained mechanics of the various skilled trades groups are available. If the management can entrust such work as alignment of shafts, scraping of bearings, packing pumps, welding, steamfitting, brickwork, and the endless variety of other mechanical skills largely to capable men, much has been gained. While local conditions will always have a decided bearing on this, it may be safely stated that such men are, in general, obtainable in most cities.

This is not true of men employed to operate a plant as involved as the combined steam power and sludge drying plants at the Southwest Works. Here there is the very real problem of training personnel.

The primary requirements for an operating engineer in the steam generation and sludge drying plant are the ability and desire to learn and an understanding of the fundamentals of boilers and heat engineering; past experience with and an understanding of electrical and mechanical equipment; physical stamina in more than average quantity; and the capacity for directing the efforts of the water tenders, oilers, and laborers assigned to his shift.

In addition to these requisites, a vast amount of instruction has been provided. Classes were conducted as frequently as could be arranged to help familiarize the operating men with the principles involved in the operation of this particular plant. All phases of boiler operation and the firing of pulverized fuel were considered.

Complete, detailed operating instructions have been, or are being, written by our plant engineering staff to be issued to the men as rapidly as possible.

Large scale, schematic drawings in color of the sludge disposal and steam generation plant, each type of turbine, boiler feeding system, and condenser water supply have been framed and mounted at strategic locations throughout the plant.

The work of drying out the two 5000 K.V.A. electrical generators provided the boiler operators with the finest kind of training. The steam demand of these units was so low during this period that it was necessary to fire the boiler intermittently. Consequently each crew was obliged to light off a boiler scores of times during a period of about two weeks. The result is that each operating crew may be considered as expert in performing this operation.

The boilers and drying system have been provided with complete, centralized, and automatic control. For the first two months of operation no attempt was made to use the automatic control. The operating men were obliged to control the firing and operation entirely by hand from the central control panel. This has been of great value in furthering the training of the men.

Correct lubrication of equipment is extremely important and may properly come under the heading of training of personnel. Each piece of equipment is listed on a lubrication chart which indicates all points to be lubricated and the type of lubricant to be used at each point. The plan is to provide each point on the equipment with a brass tag which may be identified with the printed chart.

The Systematizing of Plant Records.—The advantage of starting a new plant with an orderly and readily accessible scheme for the filing of records is obvious. The self-indexing filing system in use at the Southwest Works is proving to be of decided value, and since it can be adapted to any sewage works, it seems worth while to describe it briefly.

The following records are filed according to this scheme, each in a separate filing cabinet:

1. Completed job orders. (This constitutes a record of maintenance.)
2. Costs.
3. Manufacturer's drawings.
4. Instruction books and parts lists.
5. Test and performance data.
6. Requisitions for spare parts.

The plant is divided into some thirty main divisions for the purpose of filing and each is given a number. Several, selected at random, are as follows:

1. Main Sewage Pumps and Auxiliaries.
2. Turbo-Blowers.
5. Steam Generation.
6. Sludge Conditioning.
7. Sludge Dewatering.
8. Sludge Drying.

Each main divison is sub-divided into its essential parts which are each given a letter. For example:

1. Main Sewage Pumps and Auxiliaries.
   - *A.* Turbines.
   - *B.* Reduction Gears.
   - *C.* Pump.
   - *D.* Lubrication System and Bearings.
   - *E.* Condensers and Auxiliaries.

Each sub-division is further classified into the components which past experience has taught will provide adequate and desirable records. For example:

1. Main Sewage Pumps and Auxiliaries.
   - *C.* Pumps.
     1. Impellers.
     2. Stuffing box shaft sleeves.
     3. Wearing rings.
     4. Packing.
     5. Priming system.
     6. Discharge valves.

With this filing system it becomes a quick operation to locate any information desired. For example, the manila folder 1–C–4 in the cabinet containing maintenance records will hold every completed Job Order authorizing packing of the main sewage pumps. A glance will determine the date on which the pump was packed, the kind of packing used and the names of the men performing the work. A glance at the cost record will indicate the charges for packing the pumps during any given interval of time.

This logical arrangement of plant and equipment provided a very helpful tool in checking the progress of the work of construction when the various contracts were drawing to a close. By its use, the problem of determining incomplete detail was considerably simplified.

The Condition of Equipment reports made out by each shift of operating men have proved to be very helpful. The basis of this report is a modification of the same logical arrangement of plant and equipment. A printed form is provided which lists in detail all the equipment which comes properly under the jurisdiction of each operating engineer. By the use of symbols the engineer can quickly indicate whether each piece of equipment is satisfactory, in need of repairs or adjustment, or out of service. In the case of required repairs he in-

serts the number of the Bad Order Report in a small space provided opposite the item in need of attention. Upon taking over a shift an operating engineer can immediately acquaint himself with the condition of all equipment for which he is responsible. This report also provides the man in responsible charge of all mechanical equipment with a rapid but comprehensive view of all important equipment in the entire plant each morning.

Placing the Plant in Operation

By the time the engineer in charge of mechanical maintenance and operation has accomplished all the preliminary preparation of organizing personnel, plant and records he will find himself equipped with a thorough and workable knowledge of practically all details required for the starting and operation of the plant.

Considering the magnitude of the Southwest project, it is remarkable that the basic design should be so free from error. The design of the automatic control, for example, was well conceived and well executed. Our experience has been that when the drying system is in operation it is almost impossible to follow the continual fluctuations manually.

Combining sludge drying with steam power is of great help in controlling the drying process because of the sample supply of heat which is normally available. A serious difficulty arises, however, when the firing conditions in the furnace have become disturbed. This usually is caused by failure of the coal supply to a pulverizer. In straight steam generation this is not serious provided there is sufficient other capacity in operation to pick up the steam load. When the drying system is in operation, and this occurs, prompt action is required of the operating men to prevent loss of steam temperature which can quite possibly result in a slug of water reaching the turbines. This is essentially an operating problem and can best be handled by thorough schooling of and constant attention by the operating men.

Just a few of the other design features which have simplified the maintenance and operation of the plant are:

Location of the vacuum filters so as to eliminate the need for elevating the mixture of filter cake and dry return sludge.

The use of chlorination to prevent formation of growths in the condenser tubes.

The installation of the fine bar screens ahead of the concentration tanks.

A lengthy discussion of the problems encountered in starting the steam generation and sludge drying plant would be of little value. A brief description of one or two should prove of more less general interest.

One of the first was slagging in the furnaces. Because of the fact that combustion practice is not an exact science, this was neither unusual nor entirely unexpected. Aside from causing outages of boilers and costly removal of the deposits on the water screen tubes, a more

serious difficulty was loss of control of the steam temperature. Since the steam lines, valves and turbines are designed for certain maximum temperatures, it was of vital importance that the condition be corrected.

In theory, the elimination of slagging is simple. Ash as it leaves a pulverized fuel burner is in tiny particles and at a temperature above the fusion point. The problem is nothing more than the cooling of these tiny particles of ash in suspension before they can touch any tube or refractory surface or each other.

This has been successfully accomplished by altering the duct design slightly to provide better control of the tertiary air, by altering the size of the secondary air ports in the front wall of the furnace so as to increase the jet velocity of the streams of secondary air, and by improving the distribution of fuel across the tips of the burners.

Another problem arose in controlling the division of drying load between two flash dryers operating in parallel. This is of more than ordinary interest. A single sludge mixer discharges into the hot tower which is divided into two sections, each of which connects to one-half of a flash dryer. Each half of the flash dryer discharges, in turn, into a cyclone separator. Due to the action of the sludge mixer, the material to be dried is not divided equally between the two parallel sections of the drying system.

The problem was to provide a means to properly proportion the sludge to be dried to the heating medium available to perform the drying. To accomplish this, a thermostat has been placed in the vapor outlet of each of two cyclone separators connected to the two halves of one flash dryer. A change of temperature in either cyclone will react through control equipment so as to move a damper located immediately below the sludge mixer in the hot tower. As this damper moves, it causes more material to be discharged into the portion of the system with the higher cyclone temperature. This control has proved to be entirely effective and dependable and installation will proceed on all eight drying units as quickly as possible.

In the sewage treatment plant, certain mechanical features which were incorporated in the design have proved to be of sufficient value to be worthy of mention.

Because of the fact that such equipment as settling tank mechanisms, screen cleaners and sludge pumps are located away from a central shop, the maintenance cost of this equipment is high. Further, mechanical failures cause interruptions of service which do not make easier the work of controlling sewage processes.

The use of totally enclosed speed reducers properly sealed and running in oil has reduced attention to a minimum. Analysis of the actual power demands of the various types of driving mechanisms permitted the design of speed reducers and selection of motors of such size as to assure freedom from mechanical failures. By driving each conveyor or screen cleaner by a properly proportioned speed reducer and motor the need for shear pins has been eliminated. If a motor stalls, it is protected electrically, and it is evident that the mechanism is loaded

up to the safe limit of all its parts. This design also adapts itself to the use of alarms to notify the operator of a shut down.

All flight conveyors have been equipped with wearing shoes fastened to a shoe holder by means of a tapered and dovetailed fit. The result is a very quick and low cost replacement as the shoes wear out since the only tool required is a hammer.

Maintenance work on screen cleaners has been greatly facilitated by a design which permits the screen and conveyor, or rake apparatus, to be rotated out of the chamber as a unit. The speed reducers driving the sludge screens are overhung on the head shaft. This permits the adjustment of the head shaft to take up wear on conveyor chains without disturbing the driving unit.

Conclusion

The degree of success obtained in starting any plant is definitely a function of the amount of orderly preliminary preparation which has preceded it. This will further manifest itself in the morale and the attitude of all employees.

The physical problems of starting, operating and maintaining the plant and equipment will be adequately taken care of, provided a competent engineering staff with proper operating experience have had an opportunity to lay the groundwork.

Industrial Wastes

TREATMENT OF SULFUR DYE WASTE BY THE ACTIVATED SLUDGE PROCESS

III. DEWATERING OF ACTIVATED SLUDGE OBTAINED BY TREATMENT OF A SULFUR DYE–SEWAGE MIXTURE*

By Ralph Porges and Henry J. Miles

Special and Former Investigators for the Textile Foundation, Washington, D. C.

Successful treatment of sulfur dye-sewage waste by the activated sludge process has been demonstrated by the authors (1, 2). However, the ultimate success of any disposal process depends upon the properties of the sludge produced and the ability to dispose of that sludge. The disposal of activated sludge is generally facilitated by one of two methods: the sludge is either digested and then dewatered, or the fresh sludge is dewatered directly. A study by the authors describing the effect of sulfur dyes added directly to digesting mixtures of ripe sludge and activated sludge, and the digestion of activated sludge produced from treating a dye-sewage mixture, will be published shortly. The application of the second method, the direct dewatering of fresh sludge, is reported in the present contribution. The object has been to ascertain the effect of sulfur dye waste upon the dewatering of activated sludge produced from treating that waste in combination with domestic sewage.

Preparation of Sludge

Sewage was pumped to a pilot activated sludge plant from a nearby main outfall sewer, and the dye waste was obtained directly from the dye machines of a textile plant prior to the addition of any rinse water. The pilot plant, which was operated on a fill-and-draw basis, consisted of a 720 gallon rectangular aeration tank and four small experimental aeration tanks, each having a capacity of 36 gallons.

At the beginning of each experimental run, a portion of the sludge developed from sewage in the large aeration tank was distributed among the small experimental units. The large aeration tank of 720 gallon capacity continued to be operated on sewage alone while the smaller experimental units were subjected to sewage mixed with 1 per cent of strongly concentrated sulfur dye waste. The small tanks were operated under similar conditions except as to the amounts of suspended solids retained in the various units, which were as follows: Tank 1, approximately 500 p.p.m.; Tank 2, 1500 p.p.m.; Tank 3, 2500 p.p.m.;

* This research project was carried out under joint sponsorship of the University of North Carolina and The Textile Foundation.

Tank 4, 3500 p.p.m. The aeration period of all tanks was 9 hours. The air was then turned off and the solids allowed to settle in the tanks for two hours, after which the supernatant liquor was withdrawn and replaced by sewage in the large tank and by a sewage-dye mixture in the small tanks. Suspended solids content of the small aeration units were maintained at approximately the stated amounts by discharging the proper amounts of mixed liquor before settling the sludge.

At the end of the final aeration period the contents of the tanks were allowed to settle, supernatant liquor withdrawn, and the settled sludge utilized for the dewatering tests. Tank 1 was omitted as 500 p.p.m. suspended solids produced insufficient sludge. Table I presents all pertinent data of the materials used.

TABLE I.—*Sludge Data*

Tank No.	Suspended Solids P.p.m.	Sludge Derivation	Total Solids Per Ct.	Volatile Solids Per Ct.	pH
Large		Sewage	1.86	54.0	6.9
2*	1500	1% Dye-sewage	2.28	77.2	6.5
3*	2500	1% Dye-sewage	1.96	76.2	6.7
4	3500	1% Dye-sewage	1.61	73.3	6.8

* Dewatered after storing over night.

EXPERIMENTAL METHODS

In these studies, the dewatering apparatus used was constructed of an 11 cm. Buechner funnel and a suction flask attached to a laboratory tap aspirator and a mercury gage. No. 202 "Reeve Angel," open texture, rapid filtering paper was used. A diagram of the set-up is shown in Fig. 1.

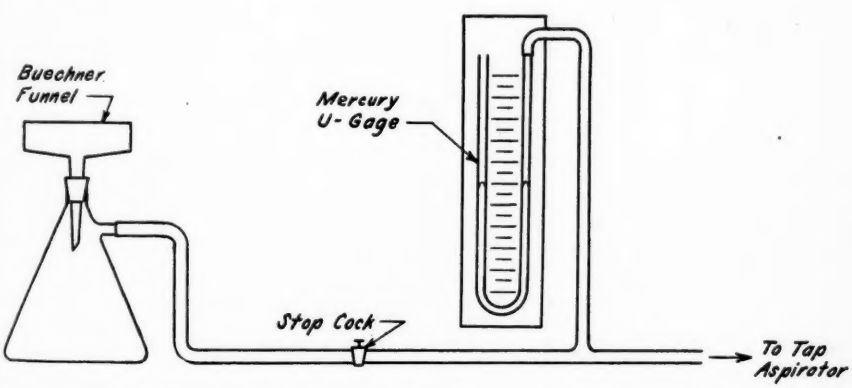
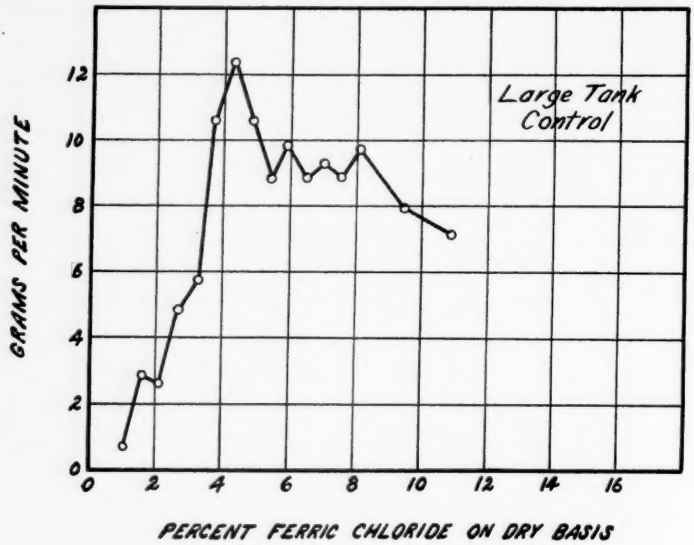
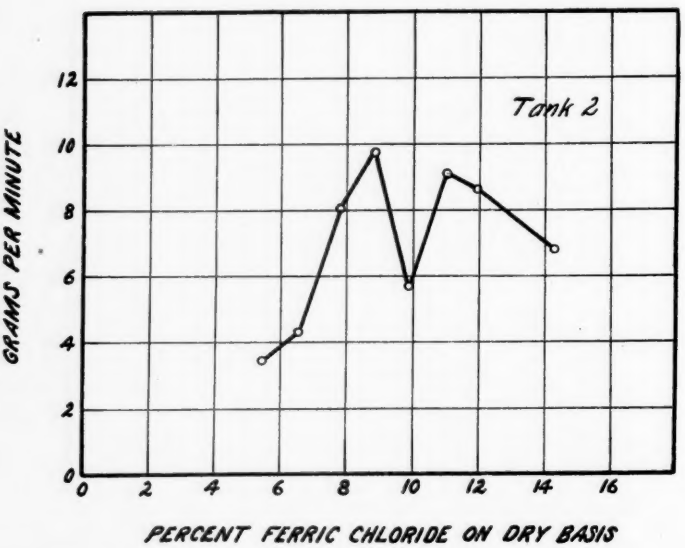


FIG. 1.—Schematic presentation of apparatus used for dewatering sludge.

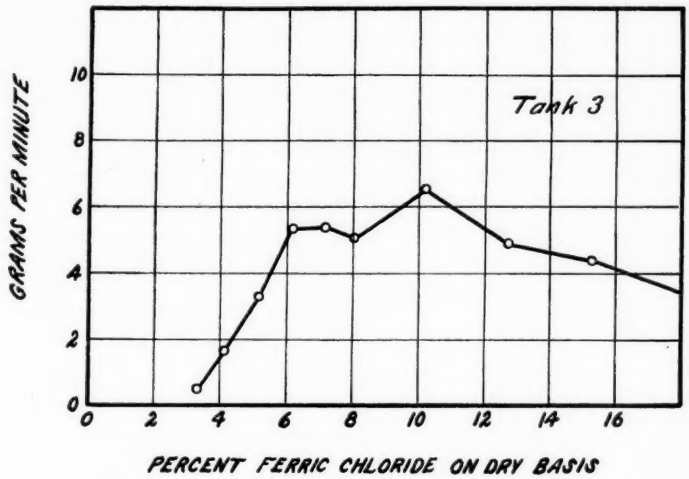
FIG. 2.—Graphs showing rate of sludge dewatering, expressed as grams of dry sludge per minute, as effected by ferric chloride, expressed as per cent of dry weight of sludge.



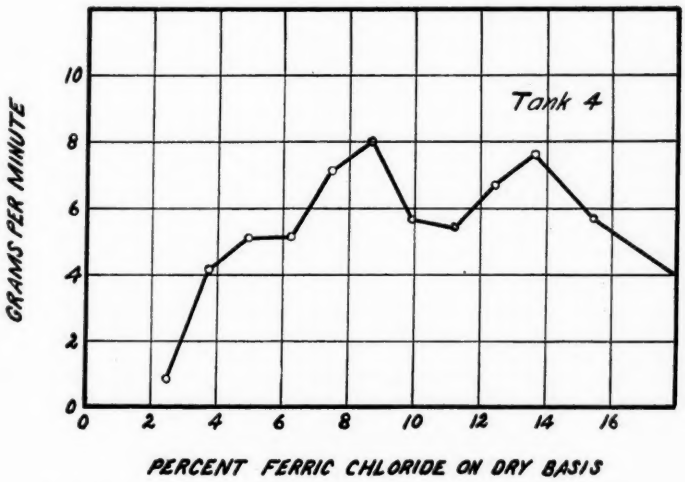
Large tank—Control containing ordinary sewage.



Tank 2—1 per cent dye and containing 1500 p.p.m. suspended solids.



Tank 3—1 per cent dye and containing 2500 p.p.m. suspended solids.



Tank 4—1 per cent dye and containing 3500 p.p.m. suspended solids.

A quantity of sludge was removed from a tank. After thorough agitation, a 200 ml. representative sample was withdrawn, to which a coagulant (10 per cent solution of ferric chloride) was then added. In order to keep the volume constant, distilled water was added to a total volume of 220 ml. The sample was mixed for one minute and immediately poured onto a previously moistened filter paper in a Buechner funnel. The stopcock was opened and the time recorded. A suction of 29 inches was obtained. As the sludge dewaters and dries the cake cracks allowing air to pass into the suction flask. This passage of air is shown instantly on the mercury gage and the time is again recorded. The filtrate was measured after each run. This procedure is modified after Genter (3).

The sludges treated in these tests were derived from the same sewage, hence the results should be comparable. Sludge from the large tank, derived from the treatment of plain sewage, was the control while sludges from Tanks 2, 3, and 4 demonstrated the effect of the waste.

Results

Results are presented graphically in Fig. 2. The rate of dewatering expressed as grams of dry sludge per minute is plotted against the amount of ferric chloride added to the sludge, expressed as per cent on the dry solids basis. Sludges from Tanks 2 and 3 were held overnight and were filtered a day after those from the large tank and Tank 4.

The large control tank, containing sewage sludge only, gave the best results with slightly over 4 per cent ferric chloride, filtering over 12 grams per minute. Sludge from Tank 2 filtered slightly under 10 grams per minute with about 9 per cent ferric chloride; Tank 3, 6.5 grams per minute with over 10 per cent ferric chloride; Tank 4, 8 grams per minute with about 9 per cent ferric chloride.

In all cases a dry and easily removable sludge cake was formed.

Discussion

It is evident (Fig. 2) that the control dewatered more rapidly and with less conditioning chemicals than the other samples illustrating that dye waste is detrimental to the dewatering of activated sludge. This effect may be the result of the dye particles clogging the filter or, possibly, the poorer condition of the sludge. Previous work (1) has shown that with a 9-hour aeration period all tanks treating a 1 per cent dye waste produced a B.O.D. removal well over 90 per cent. The sludge settled readily, appeared to be in good condition and, although colored by the waste, no accumulation of dye could be determined even after three months continuous operation. This would indicate that the sludge used in these experiments was in good condition and that the reduced rate of dewatering was caused by the dye particles adsorbed by the activated floc.

A comparison of the curves for Tanks 2 and 3 shows the effect of

various quantities of dye. The authors have stated (2) that color removal increases proportionally to the solids in the aeration tanks until a concentration of between 2500–3000 p.p.m. is reached. It was found that Tank 2 removed about 55 per cent of the color and Tank 3 about 70 per cent. Since it was necessary to discharge solids at a higher rate from Tank 2 in order to maintain the suspended solids of the mixed liquor at approximately 1500 p.p.m., the discharge of these solids removed a considerable amount of adsorbed dye. Therefore, Tank 3, containing 2500 p.p.m. suspended solids should have contained more dye than Tank 2. That such was the case is illustrated in Fig. 2 by the reduced filtration rate of sludge from Tank 3, which at the same time required more conditioning chemical.

A comparison of the graphs obtained with sludge from Tanks 3 and 4 illustrate the effect of storing sludge for a period of time before dewatering. In the course of these studies, it was necessary to retain sludge from Tanks 2 and 3 until the following day, before dewatering. Sludge from Tank 3 required more conditioning chemical and gave slower filtering rates than those obtained with sludge from Tank 4. This is in agreement with Fugate and Stanley (4) who reported that to assure rapid dewatering, activated sludge must be brought from the settling tanks and filtered immediately.

Summary and Conclusions

Dewatering tests were conducted on activated sludges originating from sewage alone and from dye-sewage mixtures. The sludges derived from dye waste-sewage mixtures were obtained from three tanks that contained suspended solids concentrations of about 1500, 2500, and 3500 p.p.m. All sludges were conditioned with ferric chloride and filtered through a Buechner funnel operated at a constant vacuum.

Approximately twice as much ferric chloride was required to condition sludge from sewage and dye mixtures as was required with sewage alone. Activated sludge from sewage showed a maximum rate of dewatering of over 12 grams per minute with a requirement of about 4 per cent ferric chloride, while the rate of dewatering for sludges from dye-sewage mixtures varied from 6 to 10 grams per minute and required 8 to 10 per cent ferric chloride on a dry solids basis.

Of the sludges obtained from the dye-sewage mixtures, that obtained from the tank containing the least amount of solids during operation dewatered best, probably because of the lesser amount of dye present in the sludge.

Activated sludge filtered immediately after settling gave better results than sludge stored overnight. Less conditioner was required and higher rates of dewatering were obtainable.

Acknowledgment

The authors wish to express their appreciation to Dr. H. G. Baity of the University of North Carolina for his cooperation in this work.

REFERENCES

1. H. J. Miles and R. Porges, "Treatment of Sulfur Dye Waste by the Activated Sludge Process," *This Journal*, **10**, 322–335 (1938).
2. H. J. Miles and R. Porges, "Treatment of Sulfur Dye Waste by the Activated Sludge Process. II. Further Studies of Optimum Operating Conditions," *This Journal*, **10**, 856–867 (1938).
3. A. L. Genter, "Adsorption and Flocculation as Applied to Sewage Sludges," *This Journal*, **6** (1934).
4. G. L. Fugate and W. S. Stanley, "Experiences and Experiments at the Houston Activated Sludge Plant," *This Journal*, **1** (1928).

PACKINGHOUSE WASTES AND SEWAGE TREATMENT AT AUSTIN, MINNESOTA *

By Paul Hansen and K. V. Hill

Greeley and Hansen, Chicago, Illinois

In discussing sewage treatment at Austin, Minnesota, it is interesting to mention a number of municipalities in the Middle West which have similar difficult sewage treatment problems, created by the necessity of providing adequate sewage treatment not only for the domestic sewage of the municipality but also for the wastes of a large and rapidly growing meat packing industry. Among such municipalities are Sioux Falls, Mason City, Fort Dodge, Cedar Rapids, Waterloo, Ottumwa, Madison and Austin.

With the exception of two of the municipalities mentioned, Cedar Rapids and Madison, the population equivalent of the packinghouse wastes is considerably greater than the population of the municipalities. Thus, at Fort Dodge the sewage treatment works are designed for a human population of 22,000, and the packinghouse wastes have an estimated population equivalent of 45,000 as measured by B.O.D. At Sioux Falls the human population is 36,000 and the population equivalent of the packinghouse wastes is 158,000. At Austin, the human population is 18,000, and the population equivalent of the packinghouse wastes is 195,000.

In all of the cases cited, the receiving bodies of water offer little dilution. In several cases the volumes of sewage and wastes exceed the flow of the stream into which they or their treated effluents must be discharged. Thus at Sioux Falls, the flow of the Big Sioux River at times is less than the combined flow of domestic sewage and packinghouse waste. At Mason City, Lime Creek has a small variable flow, which at times does not exceed 10.0 M.G.D. At Austin, during the winter months when the flow of packinghouse waste is a maximum, the discharge of the Cedar River may fall to 16.0 M.G.D. At Madison the effluent of the sewage treatment plant finds its way into Lake Monona which is used extensively for recreational purposes.

Varied arrangements exist between the municipalities and the packing houses in attempting to solve their sewage treatment problems. This results in part from the individuality of each packinghouse, the highly competitive nature of the industry, the reluctance of a competitive industry to enter into a long time agreement with a municipal utility, and the fond hope of the industry to recover a valuable by-product from the wastes of its production processes. At Austin and Madison the packinghouses operate their own sewage treatment plants which are of the nature of pre-treatment plants and involve attempted recovery of saleable products. Effluents of these plants are discharged

* Presented at the Twelfth Annual Meeting of the Central States Sewage Works Association, Chicago, Ill., Oct. 12, 1939.

into the city sewers for further treatment along with domestic sewage. At Mason City the packinghouse gives complete treatment to its own sewage without attempted recovery. At Sioux Falls the packinghouse is now considering abandoning its pre-treatment plant and entering into an agreement with the City to treat the raw packinghouse wastes.

The Sewage Treatment Problem at Austin

The problem of sewage treatment at Austin presents an unusually difficult combination of factors, namely, the high population equivalent of the wastes, their small volume, and the necessity for a great reduction in oxygen consuming organic matter to prevent pollution of the Cedar River which at times affords little dilution and little available oxygen.

Briefly, the sewage treatment works at Austin must handle the wastes from an equivalent population of 80,000 people, concentrated into an average flow of 4,000,000 gallons per day. The works must be capable of producing an effluent containing less than 30 p.p.m. 5-day B.O.D.

Local Data

The City of Austin is in southeastern Minnesota, approximately twelve miles north of the Iowa state line. The Cedar River which is the natural drainage channel of practically the entire area within the city limits has a drainage area above Austin of 425 square miles. Gaugings of the river flow indicate that for at least 12 per cent of the time the discharge of the river at Austin is less than 30 cu. ft. per second, and 5 per cent of the time less than 25 cu. ft. per second. The main industry of Austin is the George A. Hormel and Company packinghouse, engaged in slaughtering hogs, cattle, calves, and sheep and canning chickens and miscellaneous food products. The Hormel Company is equipped to kill a total of 2,000,000 pounds of animals per day.

Historical

For many years the pollution of the Cedar River below Austin has been the source of complaints from private individuals, organizations and municipalities. In 1923 consulting engineers, employed by the city to study the problem, recommended treatment of the mixed domestic sewage and industrial wastes by sedimentation and trickling filters. At that time, an agreement could not be reached between the city officials and the packing company for mixed treatment. In 1925 the city constructed a treatment plant for city sewage only, consisting of a pumping station, Imhoff tanks, a tricking filter, a final sedimentation tank and sludge drying beds About the same time, George A. Hormel and Company installed fine screens and a settling tank for removing paunch manure and other suspended solids from part of the packinghouse wastes before their discharge to the river. In 1930 experiments were begun under the direction of Dr. H. O. Halvorson at the packing plant

with heavy chlorination as a means of coagulation and direct oxidation of the packinghouse sewage. It was also the expectation to recover saleable tankage. The results of these experiments led to the installation of equipment which has been operated continuously, except for occasional breakdowns, since October 1930, but without greatly improving the condition of Cedar River.

In 1930–32 the Minnesota State Board of Health in collaboration with the Minnesota Department of Conservation and the Iowa State Department of Health made an investigation and report on the sanitary condition of Cedar River The report indicated that the city plant was overloaded and that the treatment given the packinghouse wastes at the packinghouse was inadequate to prevent pollution of the river. The report indicated further that the untreated packinghouse wastes which were discharged to the city sewers were responsible in large measure for overloading the city sewage treatment plant.

In November, 1936, the city engaged Greeley & Hansen to investigate and report on sewage disposal. Various methods of treatment were considered including activated sludge, chemical precipitation, the Guggenheim process, and double filtration. The last mentioned process combined with sedimentation and separate sludge digestion proved most economical due in large measure to the availability of the existing trickling filters.

Construction of the new works was started in January, 1939, and they will be put into operation in December, 1939.

Pre-Treatment of Packinghouse Wastes

As previously stated, part of the packinghouse wastes have been given treatment at the packinghouse since 1930. The treatment consists of heavy chlorination of these wastes, plus sedimentation. This treatment is effective in removing a considerable amount of dissolved proteins and suspended matter. Sludge removed from the sedimentation tanks contains as high as 13 per cent solids. B.O.D. of the wastes is reduced from about 2,000 to from 600 to 800 parts per million. Suspended matter is reduced from about 1900 to 200 parts per million. Sludge removed by the sedimentation process is centrifuged and then flash dried.

At present the packinghouse officials are considering abandoning heavy chlorination and sedimentation in favor of sedimentation and high rate filtration of the sedimentation tank effluent. Results of experiments to date utilizing this method of treatment indicate that it is possible to reduce the B.O.D. of the wastes about 70 per cent by recirculating them three times through the filters. Consideration is also being given to chemical precipitation as an aid to the treatment.

Under an agreement between the city and the packinghouse, the packinghouse is required to so pre-treat all packinghouse wastes that the wastes discharged into the city sewers will not contain more than 600 p.p.m. 5-day B.O.D. or more than 200 p.p.m. suspended matter.

Description of New Work

The new sewage works at Austin (Fig. 1) comprise a mechanical bar screen and screenings grinder; an equalizing tank, with capacity to smooth out hourly variations in flow of sewage and packinghouse wastes

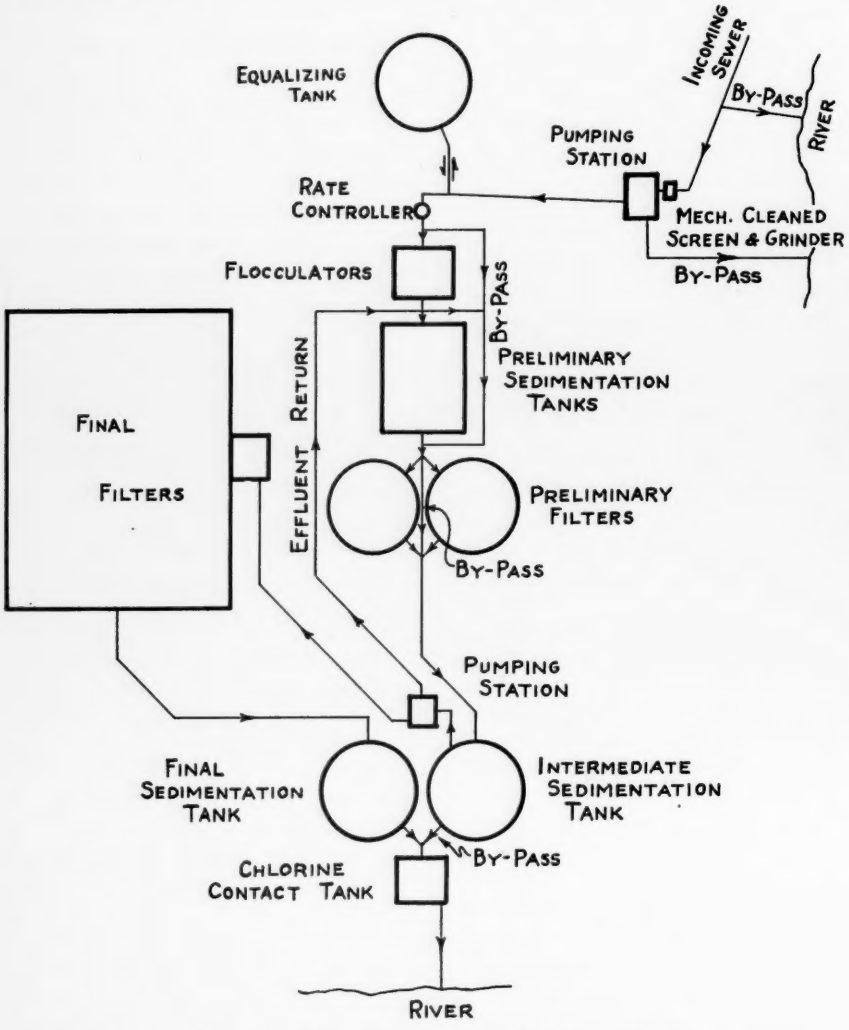


Fig. 1.—Austin, Minnesota, Sewage Flow Diagram.

going through the plant; flocculating equipment; preliminary sedimentation tanks (Fig. 2); preliminary filters of the so-called "high rate" type; intermediate sedimentation tank; final filters, final sedimentation tank and a chlorine contact tank. The existing pumping station has been rehabilitated and new sewage pumps have been installed.

An intermediate pumping station has been provided for pumping the effluent from the intermediate settling tank to the final tricking filter and for pumping final effluent into the influent of the preliminary filters. Four dry feed machines are included for applying coagulants to the sewage, and chlorinating equipment is installed for both prechlorination and post-chlorination. Sludge digestion is provided for by two-stage (Fig. 3) digestion tanks. The existing Imhoff tank is to be used for sludge storage. New sludge drying beds have been constructed, to supplement existing drying beds, and, in addition, there is a large sludge lagoon on the site.

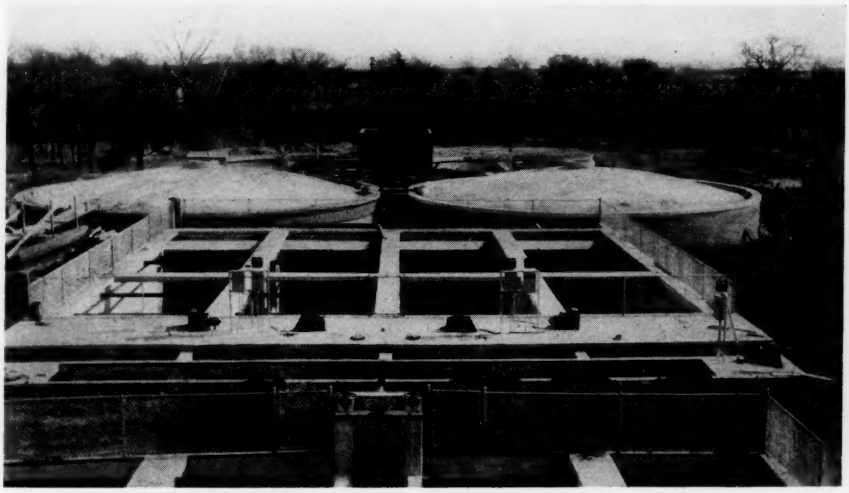


FIG. 2.—Flocculating Tanks, Preliminary Sedimentation Tanks, Preliminary Filters. Intermediate Pumping Station, Intermediate and Final Sedimentation Tanks.

Raw sewage flows are measured by the Venturi meter used in connection with the rate controller on the equalizing tank outlet. Meters are provided on all sludge lines, and the dosing tanks on the final filters are equipped with counters.

Features of design of principal interest are the revamping of the existing pumping station to provide greater space and more pump capacity and improved screening arrangements. In the existing pumping station before revamping, screenings were removed by hand raking from a screen extending the length of the wet well and elevated to the pump room floor by rope and bucket. The new screening arrangements provide for mechanical cleaning of the screen with mechanical comminution of the screenings and their return to the wet well. Control of screening and grinding is accessibly located on the ground floor.

Another feature of design worthy of mention is the attempt to make use of devices to overcome the strength of the sewage progressively, rather than largely in one or two treatment devices. The first of these devices is the equalizing tank which is designed to smooth out the peak

FIG. 3.—Sludge Digestion Tanks.

flows which might otherwise overload parts of the treatment process. Figure 4 indicates the hourly percentage variation in sewage flow. Figure 5 is a mass diagram based on the cumulative hourly pumpage and indicates the amount of storage necessary to permit operation of the plant at a uniform rate over 24 hours. Next is the flocculator and chemical feeding equipment which later will be used only at times of heavy loadings on the plant and low stream flows. Next the preliminary filters which are designed to remove only part of the B.O.D. of the sewage. Finally the facilities for post-chlorination which can be used to postpone decomposition of the effluent until the plant effluent

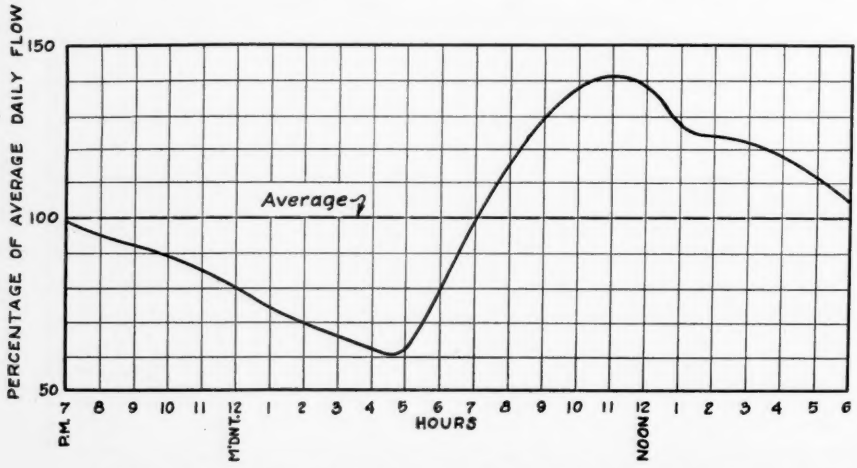


FIG. 4.—Austin, Minn., Hourly Percentage Variation in Sewage Flow.

has reached a stage in the river where reaeration will provide sufficient oxygen to satisfy the oxygen demand.

The two 68 ft. diameter preliminary filters are covered with concrete domes of the Hewitt type. The existing trickling filter was also covered with a substantial brick superstructure with treated lumber roof. This superstructure displaces an old wood and stucco superstructure which disintegrated rapidly under the action of moisture and frost.

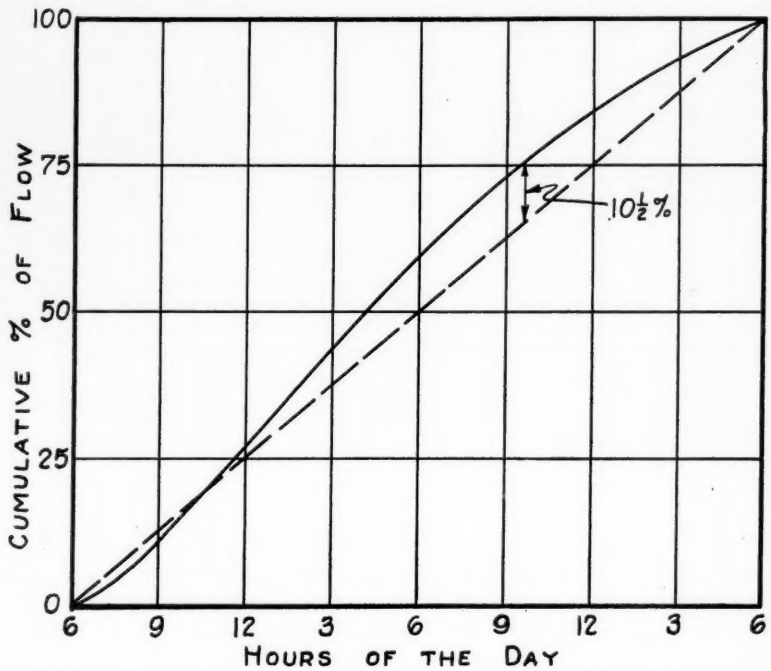


FIG. 5.—Austin, Minnestota, Storage Required to Equalize Variations in Flow.

FLEXIBILITY

As already suggested, all of the devices embodied in the treatment plant need not be used all of the time. The operator is expected to observe the available oxygen in the receiving stream and to adjust the treatment to economically obtain adequate reduction of B.O.D. within the ability of the stream to provide a reasonable surplus of oxygen. The omission of chemicals represents the first permissible and desirable reduction in treatment. This effects a direct saving. It is anticipated that coagulants and chlorine will be required on an average of about thirty days during the year. During some years chemical treatment may not be necessary at all. At times of relatively high water it will be unnecessary to use the secondary filters, and thus the cost of pumping to these filters may be saved. Heavy chlorination of the final effluent will be necessary only in extreme low water as a means of retarding

decomposition to keep pace with reaeration of the stream water and as a means of direct oxidation. With two sets of filters, preliminary and final, it will be feasible under favorable stream conditions to permit relatively prolonged resting periods. Observation of the existing filters has indicated a surprising cleansing effect resulting from idleness during the period of construction. The various combinations of treatment that can be worked out will give the operator much latitude for economy. On the other hand, the relative complexity of the plant places an obligation on the operator of maintaining good analytical control, and of exercising judgment and skill with a view to securing acceptable results economically. This may appear to be placing too much burden upon the plant operator. Such would be the case were sewage treatment plant operation in early infancy and were there no qualified operators available. However, principles of operation are established and there is no shortage of qualified operators.

Basis of Design

The design of the new works is predicated upon treating a sewage containing 480 p.p.m. 5-day B.O.D. and 250 p.p.m. suspended matter, to produce an effluent containing not over 30 p.p.m. B.O.D. and 25 p.p.m. suspended matter.

The table below indicates the strength of the sewage as measured by the B.O.D., and the removals of B.O.D. which are expected from the various treatment plant devices.

	Per cent Reduction	B.O.D. P.P.M.
Raw Sewage		480
By Flocculation and Sedimentation	35	
Influent to Preliminary Filters		312
By Preliminary Filtration and Int. Sedimentation	55	
Influent to Final Filters		140
By Final Filtration and Sedimentation	75–80	
Final Effluent		30

Construction Cost

The construction costs for the additions to the sewage treatment works, based on contracts awarded, are shown below in tabular form.

Contract *A*—Brick Veneering Existing Pumping Station Superstructure	$ 2,300
Contract *B*—General Construction	337,000
Contract *C*—Pumping Equipment	10,022
Contract *D*—Electrical Work	8,394
Total	$357,716

Austin, Minnesota

Basis of Design—Sewage Treatment Plant

Population

1930—U. S. Census	12,276
1937—Keiter Directory Co.	17,700
1953—Estimated connected to Sewers	18,800

Sewage Flows

Average dry weather flow—Domestic	1.67	M.G.D.
Packinghouse	2.33	M.G.D.
Total	4.00	M.G.D.
Maximum Daily Flow	6.0	M.G.D.
Pumps Installed	2– 2.0 M.G.D.	
	2– 4.0 M.G.D.	
Total	4–12.0 M.G.D.	

Sewage Characteristics

	Parts per Million	
	B.O.D.	Susp. Matter
Domestic	300	300
Packinghouse	800	200
Combined Flow	480	240

Equalizing Tank

Provides storage for 10.5 per cent of average 24-hour flow.

Flocculation

4 tanks, 36 ft. 6 in. long, 10 ft. wide, 10 ft. water depth
30 minutes' displacement @ 4.0 M.G.D.

Preliminary Sedimentation

4 tanks, 73 ft. long, 15 ft. wide, 10 ft. water depth
2 hours' displacement @ 4.0 M.G.D.

Preliminary Filtration

2 Filters, each 68 ft. diameter, 6 ft. deep
Rates varying from 15.0 to 24.0 M.G.A.D.

Intermediate Sedimentation

Single Tank 70 ft. diameter, 8 ft. side water depth
1040 Gal./Sq. Ft./24 Hrs.
1.35 Hours' displacement @ 4.0 M.G.D.

Final Filtration

4.45 M.G.A.D. @ 4.0 M.G.D.
0.9 Acres, 8 ft. deep
B.O.D. loading 650 lb./Acre Ft./Day

Final Sedimentation

Same as intermediate sedimentation

Contact Tank

1 tank, 35 ft. by 33 ft. 6 in., 5 ft. water depth
15 minutes' displacement @ 4.0 M.G.D.

Sludge Digestion Tanks

Primary Digester—50 ft. diameter, 22 ft. side water depth
*Secondary Digestor—50 ft. diameter, 19 ft. side water depth
2.5 lb. dry solids per cu. ft. per month

Sludge Storage

In old Imhoff tank	118,000	Cu. Ft.
In Lagoon	1,000,000	Cu. Ft.
Sludge Drying Beds	44,900	Sq. Ft.

* 3,800 Cu. Ft. Gas Holder Cover.

Operators' Reports and Suggestions

W. D. Hatfield

249 Linden Place, Decatur, Ill.

FINE SCREENING OF SEWAGE *

By Joseph A. Muldoon

Supt. of Sewage Treatment, Bridgeport, Conn.

The use of fine screens for the purpose of removing from the sewage a part of the suspended solids is a recognized method of sewage treatment. Fine screens may be used either to remove visible objectionable matter which would otherwise appear on the surface of the watercourse into which the screened sewage is discharged, or to lessen the suspended solids reaching subsequent stages in the plant.

As the sole method of sewage treatment, fine screens are limited to locations where nuisance from floating solids is the only factor to be considered, or where lack of space, or the reduction of odor nuisance, or other restrictions, make it impracticable to employ sedimentation.

As an adjunct to other treatment processes, fine screens have been installed preliminary to treatment in settling tanks to lessen the quantity of scum; to lessen the amount of sludge and the accumulation of coarse solids in the bottoms of aeration tanks in a number of important activated sludge plants; and ahead of tank treatment to remove solids that would tend to clog nozzles of trickling filters. They have also contributed their share to the successful treating of wastes from packinghouses, and from the wool, fur, textile and hat-making industries.

While not looked upon with too much favor by engineers generally, nevertheless, fine screening still seems to attract considerable attention. While I have no current data available, the figures of about 1932 show that of the people living in cities exceeding 100,000 in population, 23 per cent of them, or about 8,500,000 people were being served by fine screens; in fact the only method that exceeded fine screening at that time was plain dilution. New York City alone had eight fine screening plants operating in 1932. The cost of installation and maintenance, however, is high in comparison with other types of treatment and that factor may be the reason for their avoidance and scarcity in the newer plants except where necessary.

Practically all fine screens are of the movable types and most of them are mechanically cleaned. The plates, or screening mediums, are generally made of bronze although a number have been made of monel metal. There are two monel screens at Norwalk, Conn., and until two

* Presented at the Tenth Annual Fall Meeting of the New England Sewage Works Association, Winchenden, Mass., Sept. 29, 1939.

years ago there was one at our Congress St. plant at Bridgeport but this has been replaced with plates built up of a silicon bronze wire.

Mostly all fine screens are of three types, viz., the drum, or barrel type like the Dorrco and Tark screens; the disc type like the Riensch-Wurl and Lincoln; and the endless belt chain type like the Rex.

Each of these types, in a restricted field, has been quite successful. A brief description will be given of the three general types.

The endless belt chain type, sometimes referred to as a band or belt screen, is very well exemplified in the Rex screen, and is made of sections of perforated screen plates fastened to endless chains. The unit is submerged at an angle into the influent channel, with the sewage passing through the perforations and the screenings being moved to an elevation above the flow by endless belts, from which they are removed.

The drum type of screen is barrel-like in design, rotating on an axis with the drum revolving partly submerged in the sewage. While the various types of drum screens have different characteristics, they operate in a similar manner. Notably large installations of this type of screen are at Milwaukee where they are used as part of an activated sludge treatment; and at the Hyperion plant in Los Angeles where ten Dorrco screens 14 ft. in diameter by 12 ft. long comprise all of the treatment given at this plant. However, a new plant that would give more complete treatment was being planned at Los Angeles when I visited there three years ago.

Perforated plates, both punched and milled, are generally used for screens. Wire cloth and mesh screens have been used in some cases but the difficulty of keeping them clean has kept them from being used very often. The openings in the perforations or slots are generally from $\frac{1}{32}$ in. to $\frac{1}{16}$ in. wide by about 2 in. long. In some special cases the slots are as much as $\frac{1}{8}$ in. wide. This sized slot would be used on the cone plates of some disc screens, the reason being that the cone sections are not submerged as much during normal flows as during storms and that the $\frac{1}{8}$ in. slots will suffice for the screening of most stormwater flows.

Due to the nature of the material removed, all fine screens will clog rapidly unless kept cleaned. This cleaning is accomplished by brushes, scrapers, or by jets of water, steam or air. Various designs of slots have also been devised to expedite the cleaning. The so-called tapered slot, with the narrow width of the slot on the top of the screen plates, has proven to be the most effective in this respect.

The disc type of screen, and that with which the speaker is more familiar, consists of a large disc covered with sections of screening plates, with the frustrum of the cone attached to the center of the disc. The whole is mounted, and revolves on a stationary shaft which is erected at an angle of from 15 to 30 degrees from the vertical, in a circular well into which the raw sewage flows. From 30 to 35 per cent of the surfaces of the disc and cone plates are perforated with milled or sawed slots that vary from $\frac{1}{32}$ in. to $\frac{1}{8}$ in. wide by about 2 in. long,

with an average, or generally used width, of 1/16 inch. However, in Bridgeport we recently replaced some worn screen plates with plates made up of a wedge-shaped wire that gives us nearly 45 per cent screening area.

The screen disc should be submerged to about half of its diameter. With more than that amount submerged the screenings will not be too well drained before they are swept off by the brushes.

As the screenings on the disc rise out of the sewage they are swept off by revolving round brushes that are mounted onto the ends of the arms of the part of the equipment known as the brush spider.

A disc screen will travel at the rate of 2 to 4 minutes per revolution, the speed being generally determined by the rate of sewage flow.

The Riensch-Wurl screen, which is probably the best known type of the disc screens, was originally developed in Germany about 1900 and even today there are many in use in that country and in its provinces of Prussia, Saxony, Hessia and Baden. From Germany their use expanded to Norway, Russia and France. Their use in Europe, however, was confined mostly to cities located on large rivers where merely the removal of floating nuisances was required.

It was not until 1915 that a Riensch-Wurl screen was installed in this country, at Daytona, Florida. Due to wide promotion by the old Sanitation Corporation, their use spread rapidly for the next ten years, particularly around the metropolitan area of New York. New York City alone installed four large Riensch-Wurl plants with ten screens varying from 14 to 26 ft. in diameter. With the great volumes of diluting water around New York the screens appeared to be doing a satisfactory job for several years; but as the river beds commenced to build up with heavy sludge banks it was soon apparent that other means of treatment would be required. The Riensch-Wurl people then realized that they would have to develop other reasons for installing their screens and they proceeded to investigate other sewage problems. In this direction they had some degree of success by tying up the screens with more complete treatments, and by improving the plain screening operation in various respects.

Sizeable installations of disc screens of the Riensch-Wurl type are located in New York City; at Bridgeport, Conn.; Rochester, N. Y.; and in Westchester County, N. Y., where there are large new plants at North and South Yonkers and at Marmaroneck.

One development in promoting the use of disc screens is that of using them as a circular filter. This is the system of operation of the Lincoln type disc screen as used at our Congress St. plant in Bridgeport. In this case the screen is equipped with a stop and start control float in the screen well. The screen is normally stopped. As the sewage flows over the screen plates the larger pieces of solids remain on the plates and commence to build up a filter blanket that catches many of the smaller pieces that ordinarily would have gone through the screen slots. This closing of the slots causes the sewage to rise in the well to a point where the control float will start the screen revolving.

As the screen revolves the cleaned plates enter the sewage flow and the flow then recedes to a lower level where the control float again shuts off the power. As the screen comes to rest the filtering process is again repeated. There is a lot of merit in this idea although some engineers are of the opinion that the weight of the sewage built up on the screen tends to force even the larger pieces of screenings through the slots. Our own experience has been that the idea is very practical and does screen out much more material than if the screen revolves continually.

In the Lincoln filter the plates are built up of monel or bronze flat wire on edge and the wires are assembled in a curve to meet the curve of the sweep of the cleaning brushes. Examples of these are the two screens at Norwalk, Conn., and one screen we had at the Congress St. plant in Bridgeport. The Lincoln has some advantages over the old Riensch-Wurl screen, particularly in regard to increased screening area, and in the curved slots which induce better cleaning. It has been noticed, however, that the built-up plates of the Lincoln screen begin to fall apart at the joints after a few years. We believe this is brought about by the vibrations in the screen as it revolves. When this condition arises you are in for lengthy and costly repairs. We had one of our screens go bad for this reason and repaired it for several years but about two years ago we replaced it with plates made up of a rolled wedged shaped wire known as the Rima wedge wire which had been used for years in the coal industry for screening washed coal. This wire gives us as much screening area and as it is possible to avoid the troublesome welded or brazed joints it makes a much stronger screen plate. We did, however, have to sacrifice the curved slot feature. After nearly two years of use we have yet to spend our first dollar for repairs on this new set of plates and their life at this time appears to be far beyond anything we have yet seen, either in the built-up plates, or the perforated or milled slot plates.

Two interesting installations of the disc type fine screens for another purpose are those at Danbury and Norwalk in Connecticut. In both places the screens are installed ahead of clarifiers. The need of disc screens at these plants was determined by the presence of fur in the sewage. Both cities have large hat factories and it was known that the fur in the sewage presented a grave sludge digestion problem.

Another example of the use of disc screens as only part of the treatment process is at Rochester, N. Y., where they have six Riensch-Wurl screens ahead of the Imhoff tanks at the Irondequoit plant. Here they are found convenient for use as skimming devices for removing the rags, leaves, garbage and other material that would float on the surfaces of the Imhoff tanks. As Mr. Lewis, Director of Maintenance and Operation says, "they serve as a mechanical skimming device, thereby eliminating the hand labor, rather than as a preliminary method of treatment for removal of a large percentage of suspended solids." The records at Rochester show that they remove only about 7.7 cu. ft. of screenings per million gallons, with slots ⅛ in. wide.

The latest development that we know of in the use of disc screens

is the recent installation at Niagara Falls, N. Y., on the Niagara Gorge just below the Falls. Here six screens with a total capacity of 50 m.g.d., have been installed. The sewage is filtered through a mat of pulverized, or small grain coke. It is fed onto a layer of coke that has been laid on the disc screens, and filters down through this medium, leaving the screenings and much suspended matter in the coke. The cleaning brushes are sensitively adjusted to sweep over the top of the coke filter mat and remove the screened and filtered material; of course, some of the coke must come with it. This loss of coke in the mat is replenished by feeding more fine coke through a hopper onto the screen as required. I have not seen the work at Niagara Falls but I did see the process when it was being developed experimentally at Norwalk some years ago. At that time they were attempting to use graded sand and gravel for the filtering medium and later used granulated hard coal. Those who saw the early attempts talked about the cost of the coal. The idea of using coal was to make the screenings more readily burnable in an incinerator. The latest improvement in the process seems to have helped the matter of fuel costs because Dr. Rudolfs reported in the July issue of Municipal Sanitation that the incinerators can be so operated as to reclaim 73 per cent of the coke by operating the incinerators to evaporate the water present and burn the solids without burning more than 28 per cent of the coke. Where they had formerly required 823 lb. of coke per million gallons they now have to use but 233 pounds.

Quoting Dr. Rudolfs' report under the heading, "General Conclusions," he says, "The Niagara Falls sewage treatment plant performed the functions for which it was built in respect to (*A*) the killing of harmful bacteria (99.99 per cent reduction); (*B*) removal of sufficient suspended solids to make proper disinfection possible (26.2 per cent suspended and 36.8 per cent settleable solids) and (*C*) to remove and destroy all floating sewage solids which may cause unsightliness, without creating smoke or odor nuisances."

The modest experiments made at Norwalk a few years ago have gone a long way to produce the results obtained at Niagara Falls and so probably the sometimes abused fine screens may still have some bright days ahead.

Installation. Fine screens should be installed in duplicate whenever possible. This will permit repairs without having to close down the plant. We have a specific example of this at our Congress St. plant where but one screen was installed and no provision made for a duplicate. As a result of this oversight it is necessary for us to close the plant for any repairs to much of the mechanism. When these repairs are of any magnitude the shutdown results in an extremely polluted river. We try to time all major repairs for the winter months to avoid the complaints that we would get had we closed down during the summer and bathing months.

Design. It has been my experience that too little attention has been given by designers and builders to the non-corrosive construction of

the understructures of disc screens. It is common to see bronze and monel plates bolted on one end to non-corrosive supports and on the opposite end to plain low carbon steel supports. This fault soon results in deterioration of the steel sections and necessitates costly repairs. No amount of painting seems to prevent this corrosion. The first cost of equipping screens with non-corrosive metals will soon be absorbed in maintenance savings.

Efficiency. The question has been asked of us many times—"How efficient are fine screens?—What is the percentage of removal?" As a matter of fact it is impossible to give a correct answer to either question. It is not practicable to ascertain even with approximate accuracy the screen efficiency by determining the suspended solids in the unscreened and screened sewage, for most of the solids removed by screening are of such a nature that they cannot be correctly sampled. One method that gives a fair idea of the work the screens are doing, is to weigh the screenings removed, determine the dry solids per million gallons and compare this value with the suspended or settling matter in the screened effluent.

Screenings. The quantity of screenings removed by fine screens depends upon a number of factors, viz.;—the width of the slots; the speed of the screen; whether the sewers are solely sanitary, or combined storm and sanitary; whether or not the sewage is pumped; and the distance the sewage flows through the system before reaching the screens. Both pumping of the sewage and flowing through the sewers will break up the larger solids and consequently reduce the amount that is screened out.

The volume of screenings will vary from 10 to 40 cu. ft. per million gallons. We have on a number of occasions at one of our plants taken a cubic yard of screenings from one-half million gallons of strong domestic sewage, but such occurrences are not frequent.

I have heard operators tell with much pride of removing 30 or 35 cu. ft. of screenings per million gallons; and other operators almost apologizing because they were getting only 10 or 15 cu. ft. It is nothing to the credit of the first nor to the discredit of the second just how much is removed if they keep their equipment in proper condition, free from holes in the plates, and the seal rings properly adjusted. The operator has no other control over the amount of removal. The nature of the sewage is something that the operator cannot control but the condition of his screening equipment is entirely his responsibility.

Generally speaking, the standard acceptances for removals by fine screens with openings $\frac{1}{16}$ in. to $\frac{3}{32}$ in. are from 20 to 30 cu. ft. per m.g.; and from 10 to 15 per cent of the suspended matter. Moisture content will be from 85 to 90 per cent; weight of screenings 50 to 60 lb. per cu. ft.; and the volatile matter on a dry basis will be from 80 to 90 per cent.

Disposal of Screenings. The handling and removal of screenings at a screening plant is as important as handling sludge from settling tanks if odors are to be controlled. Screenings contain from 90 to 95 per cent moisture, soon become offensive, and tend to decompose

quickly. Their disposition, therefore, many times becomes difficult. However, prompt attention to their removal, particularly in the warmer months, will relieve this nuisance to a great extent. A common method of disposal practiced at many plants is by burial. Metcalf and Eddy say, "if screenings are to be buried they should not be too deep as they decompose slowly if removed from the upper layers of soil known as the 'zone of living earth' in which bacterial activity is greatest." This bears out our own experience—up to about six years ago we buried our screenings in pits 18 to 20 ft. deep and covered them with from 1 to 2 feet of earth. One of these piles is in a mound in the rear of our main plant and every once in awhile someone will cut into the side of this pile and the odors that emanate are very strong indeed despite their having been under cover for six years. Our State Department of Health has permitted burial but insists upon shallow ditches with not less than a foot of earth covering.

For many years our local Park Department thought that the screenings had some fertilizing value when used to make a compost. The screenings were allowed to accumulate in a large pile in the rear of our main plant from where they were carted twice a year to one of the parks and built into a compost pile with other ingredients. However, the high odors that generated from the stock pile at our plant during the summer months finally brought some very concerted action from our nearby neighbors who threatened to do some terrible things with baskets of samples. We received sudden and drastic orders one day to stop this storage and to cover the pile at our plant.

For some time after that we carted them to the garbage reduction plant that was serving our city. We again found ourselves no end of nuisance to the operators of that plant. The garbage plant burned down one night and once again we were on our own without a home for our screenings. We then resorted to burying them in large deep pits again on the outskirts of the city but the cost of digging the pits and the troubles encountered in trucking soon discouraged that method.

About that time our new municipal garbage and rubbish incinerator had been built, in the planning of which the incineration of the screenings had been included. When the new incinerator went into operation we found new opposition because of the high amount of moisture in the screenings and we were forced to do some dewatering before the screenings could be satisfactorily incinerated. Even with the dewatering we had to fight our way with the incinerator fellows but we stood our ground and for the time being we appear to be having a permanent method of disposal for our unpopular screenings.

At our larger plant we dewater with a Louisville drying machine—this is, a roll press ordinarily used by brewers for dewatering brewery grains. One of these dryers but much larger than ours is used at the big Hyperion plant in Los Angeles for the same purpose. The dewatering is done by feeding the screenings onto a flat perforated endless steel belt that passes through two pairs of cast iron rolls. It is possible to reduce the moisture to 65 per cent but our practice is to

bring it down to about 70 or 75 per cent, at which the screenings can be readily incinerated in the municipal incinerator; the higher moisture permits us longer life to our dryer belts.

At our other screening plant we dewater the screenings to about 80 per cent by draining them in mesh screened-bottom buckets that receive the screenings direct from the screen. We have found that they can be incinerated with this amount of moisture by mixing with the garbage and rubbish.

The plants at Milwaukee and at Jamaica, N. Y., use centrifuges for dewatering screenings before incinerating, with apparently satisfactory results. The Westchester County plants at Yonkers and Marmaroneck dewater with roll presses of their own design. All of these plants, however, have their own incinerators.

Some seacoast towns barge their screenings to sea and other towns plough them into the ground of nearby farms. There is, however, the possibility of danger from this latter method. At one time we gave some of our screenings to farmers for this use but our State Health Department does not encourage it, particularly if the plot is to be used to raise root or ground vegetables such as potatoes, beets, turnips and the like.

Maintenance. With all due respect to the scientific aspects of fine screens, the mechanical maintenance demands most of our attention. There is a limit to the effectiveness to which a fine screen can be brought, but unless the mechanical equipment is kept in constantly good condition, that standard of effectiveness will be greatly reduced. It is most essential that repairs and improvements be kept up all the time. To accomplish this a mechanically minded operator will find plenty to occupy his mind.

The proper maintenance of a screening and pumping plant requires the efforts of a trained personnel. The severe conditions under which the machinery and equipment operate, needing repairs and replacements regularly, necessitates having capable men available. Because of the system used in furnishing operators in some plants the picking at many times is not too choice; but every effort should be made to see that the personnel includes a good all-around repair machinist and an electrical man with some power house experience; the ordinary house electrician is of little use; it is also very desirable to have among the operators a man who has had some experience in millwrighting and who can also do some pipe fitting. With such a nucleus your personnel will be well balanced.

After personnel I believe that the next important factor for good maintenance is lubrication. The proper and complete lubrication of screening equipment can never be too often or strongly emphasized. Such equipment is composed mostly of heavy slow moving parts under very heavy loads and proper lubrication is sometimes difficult. The builders and designers of screening equipment have too many times fallen short in providing proper and efficient lubricating means. Where grease is used a good grade of non-soluble grease made with a high

grade cylinder stock should be provided for every suitable use. High pressure lubricators should be used exclusively—at Bridgeport we use pressure grease guns that can develop 2,000 lb. pressure. Individual lubricators for each bearing are the most dependable. It will take longer to lubricate the bearings individually but the time will be well spent. All of the so-called one-shot lubricating systems have been removed from our equipment and replaced with single fittings. Many experiences have shown us that the one-shot systems are not dependable; a line can become clogged or broken and not noticed if the one-shot system is being used; individual lubricating would bring these faults to light.

In my opinion, based on many years of experience, high grade grease lubrication is the most practical and efficient form of lubrication. The tendency of the soaps in the grease to retain the oils and to adhere to the surfaces of the bearings of slow moving parts such as in screening equipment make it the ideal form of lubrication.

On the market today there are many grades of grease at all kinds of prices and the purchaser must ever be on his guard. Many purchasing agents make the serious and expensive mistake of buying inferior lubricants on price alone. The testing of lubricants should be done without any thought of price in mind; an operator should exercise great care in making his selections and allow no one to bias his decisions. Many barrels of the best lubricants can be bought for the cost of replacing a main screen bearing that failed because of poor lubrication. The best lubrication is always the best even in the short run.

I have picked out a few problems of maintenance that have annoyed us from time to time. Among these are the screen thrust bearings, the screening plates, sewage plant metals, screen seal rings and vertical pump shaft bearings; and these items will be mentioned in that order.

The weight of the large screening discs is supported on a ball thrust bearing located on the upper section of the main stationary shaft. Many very poor designs of these thrust bearings are in evidence; most of them are too small to support the loads exerted; others fail to provide a self-aligning arrangement, which results in uneven loads on the balls as the shaft bearing liners wear, and this brings premature destruction of the ball thrust bearings. Still other designs have gone to an extreme type of combined radial and thrust bearing that takes most of its lead radially, whereas most of the load on the screen is direct thrust with comparatively little radial. If the use of screens of this type is to continue the designer might well give more study to the matter of ample and suitable thrust load support. The labor costs for disassembling a screen for a main bearing replacement is excessive and any necessary first cost that would assure a satisfactory installation would be a wise investment. We had this trouble at Bridgeport in a bearing that would last but two years; after several replacements of the original type of bearing we called in the engineers of a good Connecticut bearing manufacturer and had them design a bearing more suited to the job. The original design of the bearing housing prevented

us from getting all we desired in the new bearing, but even with this handicap we were able to get a bearing that now lasts four to five years. A properly designed bearing should last at least ten years, if it is made of sufficient size and kept well lubricated.

It is essential that the brushes be kept in good condition at all times if your screens are to be properly cleaned. The bristles in the brushes should be the best obtainable, and the fillings or tufts should be entirely free from the strands of fiber that some unscrupulous brush manufacturers will use to "lead" up the tufts. The fibers are used to make an inferior grade of bristles appear stiffer and also to cut down on the quantity of bristles required. These fibers are easily discovered and when rebristling is ordered it should be specified that no loading with fillers will be permitted. Our experience has shown us that it is real economy to use the best of genuine boar bristles. As a result of our study of brushes we have been able to get double their life at half what it cost us when we first commenced to buy brushes.

Another practice worth following is that of reversing the brushes, end for end, every month. This not only tends to make the bristles wear more uniformly but straightens up and stiffens the bristles that had been bent down by the continuous sweeping action. The life of the brushes will be considerably lengthened if reversed as suggested.

While hot water and steam are used in many places for the cleaning of brushes we have found that kerosene, or range oil, from a plain garden sprinkling can gives us very satisfactory results. A two-gallon can of kerosene is sprinkled onto the seven brushes every eight hour shift. The sprinkling is most effective if done while the brushes are revolving.

Many of the brushes used today are made up in sections on wooden backs and apparently much progress has been made in this direction in recent years. When our Congress St. plant was put in operation in 1929 it was equipped with the wood back brushes but in a short time the wood expanded from the moisture to such an extent that the sections forced themselves away from the holding flanges and the entire brushes collapsed. These were superseded by one-piece round aluminum shells that solved the problem for several years until it was discovered that the aluminum was disintegrating from an action set up by contact with the sewage. We discussed this trouble with the engineers of the Aluminum Company who have a plant nearby us and they made us up some castings from an alloy that they claimed would withstand the action. It appears as though they have corrected the trouble as we have had some of the newer castings in use now for several years and they are still in good shape.

The screens at Bridgeport have none of the protections afforded by grit chambers as neither of our plants was built with grit chambers and as a result the wear on the screen plates is greater than if we were so protected. The life of our screen plates was formerly about five years but about 1931 we drifted away from manganese bronze plates and had a set made up of a silicon bronze manufactured in Connecticut.

After nearly nine years of use this set is still usable and looks good for another year or two. To us this is a remarkable service in view of the excessive grit wear we have to contend with. The same silicon bronze was used when we ordered a set made up of wedge shaped wire for our other plant in 1937. In fact, the use of the same brand of silicon bronze has spread in our plants for many other purposes such as bolts, nuts, washers, tie-rods, etc. We have also made some large control floats from this metal with brazed and welded joints. These have outlasted the copper floats four to one.

The use of the silicon bronzes and the newer alloys of aluminum are well worth the study of sewage plant designers and operators.

The maintenance of the stationary seal rings, or seal segments, fastened to the screen well around the periphery of the screen are of the utmost importance. It is a waste of effort to maintain good brushes, good screen plates and slots, if the seal rings are neglected. Our State Health Department engineers check the openings between the screen rim and the seal rings with a $\frac{1}{16}$ in. gauge and it means a red face for the operator if the opening is not correct. For years we used plain grey iron unmachined castings about 2 ft. long for the segments of the seal ring. When cast, and even while laying around the plant, these castings would warp out of shape and it was a big, and still unsatisfactory, job to try to file them to conform to the shape of the screen rim. After a few years we finally got around to investing about $50 in a pair of master profiling templates made to fit a milling machine and now all of our segments are machined accurately to shape for about a half-dollar each. We also recently made a change in the material we had been using for these segments, going from grey iron to a nickel iron alloy used by one of our local machine tool builders with much success. The use of the nickel iron alloy has more than doubled the life of these parts. The steel and iron cap screws that were formerly used for clamping the seal ring segments into the screen well have also been replaced with silicon bronze screws and washers. Regular inspection and adjustments to the seal ring are made every two weeks without fail.

If you have any of the old style babbitt-lined shafting hanger boxes supporting booster pump line shafting, the use of ball-bearing pillow blocks is well worth your consideration. We had such installations in two of our boosting stations that caused us continuous concern and worry. As the operator of the boosting stations was only at the stations intermittently it was necessary that they be as free from trouble as it was possible to make them. It was a common occurrence for us to be called out at any hour of the night because of shafting boxes going bad. In trying to find a remedy for the condition we looked into the possibility of ball bearing boxes, but the bearing people refused to stand back of the 1100 r.p.m. speed of this shafting. Despite their protest, we installed the ball bearing boxes six years ago and haven't spent a cent for repairs yet.

In one of our plants we are equipped with a battery of four antiquated water works pumps totalling 45 m.g.d. capacity. Rare is the day that one of these relics is not under repairs. Never adapted to sewage work, and pumping sewage heavy with grit, the replacement of seal rings and packing sleeves is almost a routine operation with us. The life of manganese bronze seal rings and sleeves seldom exceeds two years. When we replace these rings and sleeves it costs us about $300 per pump. We are now trying a set of rings made of a modified monel and nickel alloy that is furnished us by one of our local valve manufacturers. The results look to be very promising but it is too early yet to make a definite decision.

Going to the other extreme we have in our other screening plant built in 1929, three vertical properly adapted sewage pumps totalling 30 m.g.d. capacity, that have not cost us more than $100 for maintenance in ten years. In fact there has not been a single part replaced or repaired in that time except one ball bearing in the head that failed eight years ago because a poor lubricant had been used previous to them. A new bearing and a high pressure lubricator fitting soon corrected that trouble.

An interesting tip to maintenance men and one that I have investigated but have not been able to apply as yet is that of metal spraying. The operation consists of spraying molten metal of any kind onto worn surfaces without distorting the part as is done by welding or brazing. I have seen the process in operation and am convinced that it has many uses in the repair field and we intend to try it very soon. That it has much merit is evidenced by the fact that it is being used regularly in the maintenance work at the Chicago sewage plants. Rather than go into what would be a lengthy discussion on the process I would refer you to the articles on sewage plant maintenance in the fall of 1938 issues of "Municipal Sanitation" by L. M. Johnson, the Engineer of Maintenance and Operation at the Chicago sewage plants. Mr. Johnson makes several references to the metal spraying process as used to advantage by them.

The operators of a screening plant have a distinct advantage over the operators of many other type plants in so far as cleanliness and odor control are concerned. Almost invariably the sewage coming to a treatment plant is quite fresh and because of the short time it spends in a screening plant it leaves the plant almost as fresh as when it entered. Therefore, there should be no excuse for unnecessary odors in a screening plant. Of course, if sewage is allowed to splash into corners it will soon become stagnant. An inch-and-a-half hose with a good force of water is one of the best tools we have in our plants for the elimination and prevention of this nuisance. The same applies to the rags and debris taken from the bar screens. For lack of attention, the bar screen areas of many of our newest and finest plants nearly always have this failing. Frequent hosing of the racks and equipment, and

prompt removal of the debris and screenings will go far in the prevention of unnecessary odors.

In plants like ours at Bridgeport where we transport the screenings through the city we have to be exceptionally careful. The trailer buckets we use have hinged lids and require daily hosing. While the trailers are being filled at the plants during the summer months they are covered with tarpaulins to prevent the gathering of flies.

The grounds around a plant should be given the same care that is given the plant equipment. It is a simple matter to keep the grounds in an attractive and pleasing condition. The first impression made on the mind of a visitor is, of course, the appearance of the plant grounds. If that impression is favorable, it will be a lasting one if the remainder of your plant is properly cared for. We operators owe it to ourselves to see that the officials and visitors are made sewage-plant-conscious. The visitors may not understand too much about the complications of sewage treatment but a good looking plant and grounds has made us many friends and boosters for sewage treatment.

To some operators visitors appear to be a nuisance. In my opinion this is entirely wrong. In most cases the visitors are officials or interested taxpayers. It is very obvious why we should be attentive to the officials; and to the taxpayers and citizens, we owe every consideration. They are entitled to know all there is about our plant and so long as we appreciate that fact, why not do it in a polite and gracious manner? I believe we should make every effort to encourage people to visit our plants. Aside from the fact that we are all inclined to be a little egotistic and like to show off our plant, the subject of sewage treatment is really an interesting subject and while the story might be boring to you at times, just remember that it is new to your caller and all that you show and tell him is opening up a new world to him. In Bridgeport we invite many groups to visit with us. Despite the fact that at the present time we have only plain screening plants to show them it is surprising how interested they become in what they see. Among the groups that make regular visits to us are: boy scout troups, grammar school and high school classes, businessmens' associations, the yearly graduating classes of nurses from the hospitals, and the nurses from the Visiting Nurse Association.

The "Welcome" mat on your doorstep will pay splendid dividends.

THE JOINT MEETING FOR SEWAGE DISPOSAL OF CERTAIN MUNICIPALITIES IN ESSEX AND UNION COUNTIES, N. J.

EXCERPTS FROM REPORT FOR 1938

Member Municipalities: East Orange, Hillside, Irvington, Maplewood, Millburn, Newark, Roselle Park, South Orange, Summit, Union, and West Orange.

ALEXANDER POTTER
Consulting Engineer

WILLEM RUDOLFS
Consultant

LESLIE E. WEST
Chief Engineer

CHARACTERISTICS OF THE SEWAGE TREATED

Joint Meeting sewage at the present time is strictly of the domestic type. Although the sewage originates in separate systems it is often diluted with a considerable amount of infiltration. At times when this happens the amounts of suspended solids and B.O.D. present in the influent drops considerably below normal and as high as 3.5 p.p.m. of dissolved oxygen shows up. For the most part the sewage arriving at the plant is in a fresh condition and has but little odor.

No by-passes or other outlets for diversion of flow from the plant exist, consequently a wide variation in the amounts of flow treated daily by the plant has been noted during the year. The average daily flow treated at the plant averaged under all conditions for the year 26.28 million gallons. Extreme dry weather flow has been measured as low as 20 m.g.d. and twice during the year daily flows of nearly 100 million gallons have been reached, caused from surface runoff and other infiltration entering the sewerage systems.

The principal objectives of the type of treatment provided deal with the removal of suspended solids and the reduction of biochemical oxygen demand. Of interest therefore is the following condensed summary for 1938:

Suspended Solids.—Average influent, 184 p.p.m. Average effluent, 61 p.p.m. Average reduction, 123 p.p.m.

Suspended Solids.—In pounds per capita per day.

Average influent sewage	0.1345 lbs. per capita per day
Average effluent sewage	0.0445 lbs. per capita per day
Removal	0.0900 lbs. per capita per day
Total weight or suspended solids removed daily	13.45 tons (dry)
Percentage of removal of suspended solids daily	66.8%
Cost of suspended solid removal per pound (dry)	$0.008

Biochemical Oxygen Demand.—Average influent, 202 p.p.m. Average effluent, 122 p.p.m. Average reduction, 80 p.p.m.

Biochemical Oxygen Demand.—In pounds per capita per day.

Average influent sewage ..... 0.1475 lbs. per capita per day
Average effluent sewage ..... 0.0891 lbs. per capita per day

Reduction ..... 0.0584 lbs. per capita per day
Total quantity of B.O.D. removed daily from sewage ..... 8.75 tons
Percentage of removal of B.O.D. from the sewage 39.2%
Cost of B.O.D. reduction per pound ..... $0.013.

MONTHLY RECORDS ON AVERAGE REMOVAL OF B.O.D., SUSPENDED SOLIDS AND SETTLEABLE SOLIDS

1938	5 Day B.O.D. P.p.m.			Suspended Solids P.p.m.			Settleable Solids Ml. per Liter		
Month	Inf.	Eff.	% Rem.	Inf.	Eff.	% Rem.	Inf.	Eff.	% Rem.
Jan.	196	131	33.2	176	68	61.4	6.42	.35	94.5
Feb.	178	117	34.3	171	69	59.6	6.64	.60	91.0
Mar.	178	120	32.6	179	70	60.9	6.90	.40	94.2
Apr.	167	112	32.9	170	65	61.3	6.15	.39	93.3
May	219	133	39.3	203	65	68.0	8.91	.32	96.4
June	208	126	39.4	194	61	68.6	8.28	.41	95.0
July	170	96	43.5	168	47	72.0	7.19	.39	94.6
Aug.	197	112	43.1	173	50	71.1	7.86	.28	96.4
Sept.	224	127	43.3	187	52	72.2	7.66	.26	96.6
Oct.	253	141	44.3	203	56	72.4	8.67	.26	97.0
Nov.	262	147	43.9	219	66	69.9	8.77	.33	96.2
Dec.	169	100	40.8	167	60	64.1	6.88	.25	96.4
Ave.	202	122	39.2	184	61	66.8	7.53	.36	95.2

PLANT AND OPERATION DATA—1938 SUMMARY

Sewage Flows:

Average flow treated (1938) ..... 26.28 m.g.d.
Maximum daily flow, average ..... 40 m.g.d.
Minimum daily flow, average ..... 18 m.g.d.

Coarse Racks.—Screenings—17 cu. ft. per day average.

Fine Screens.—Screenings, which are now ground up and returned to sewage average 95 cu. ft. per day or 3.73 cu. ft. per m.g.

Grit Chambers.—Grit—172 cu. ft. per day or 6.54 cu. ft. per m.g.

Triturator.—Handles at present 95 cu. ft. per day in an average of 2.35 hrs.

Primary Sedimentation Tanks:

Type—4 rectangular mechanically cleaned, each 75 ft. wide, 280 ft. long and 13 ft. deep.

Detention period (using two tanks only)

At average daily flow—26.28 m.g.d.—3.20 hrs.
At maximum daily flow—40 m.g.d.—2.10 hrs.
At minimum daily flow—18 m.g.d.—4.66 hrs.

Sludge withdrawal—Daily.

Scum removal—As required, averages twice weekly, approximately 1 cu. ft. per m.g. treated.

Sludge removal—72,608 gals. per day, or 368 cu. ft. m.g.

Sludge Concentration Tank:

Type—Circular concrete 22 ft. diam., 14 ft. deep. Capacity 38,233 gallons. Has picket fence type arrangement for mixing sludge or scum and chemicals if desired.

Sludge Storage Tanks:

Type—Two circular concrete tanks, floating covers. 70 ft. diam., 23.8 ft. side depth. Capacity 626,000 gallons or 2730 tons of sludge each.

Operation—Continuous.

Reduction in volume effected—By controlled decantation. 30,150 gallons daily or 41.5% of fresh sludge.

Disposal of sludge—Twice monthly by barging to sea.

Plant and Operation Data Discussion:

a. Flow.—Comparing the average daily amounts of sewage flow handled during 1938, with those observed during 1937 we note that they are very nearly the same: 26.28 m.g.d. as against 25.80 m.g.d. or an increase of 0.48 million gallons a day.

Typically the flows observed during the first four months of the year show the effects of infiltration, the next seven months the characteristics of dry weather flow.

On July 23rd, 1938, and again on September 21st, 1938, unusually heavy storms caused many sewer overflows in the system and built up plant flows of nearly 100 million gallons a day, with instantaneous peaks of full plant capacity or 172.5 million gallons. Fortunately no damage resulted therefrom.

b. Screenings.—During 1938 a radical change was made in the handling of the screenings produced by the plant. Prior to June screenings were pneumatically discharged to the meadows for use as fill. From June on the screenings were ground up and returned to the sewage. The record indicates that 151 cu. ft. a day were handled before grinding and only 95 cu. ft. a day afterwards. This difference is explained by a change in operation procedure. Before the grinding of screenings was practiced it was the custom to pass on to the mechanically operated bar screens the rags intercepted by the bar racks since all of the material was eventually to be disposed of in the meadowland. After installing a machine and after a short trial period it was found to be advisable to withhold large rags from the grinder for better mechanical operation, consequently the rags from the bar racks are disposed of separately. These now average 17 cu. ft. daily or about ⅔ cu. ft. per million gallons

c. Grit.—The amount of grit produced daily was reduced from 242.5 cu. ft. a day in 1937 to 172 cu. ft. a day in 1938. Probably caused

by better control of operation as to prevailing velocities in the chambers and a cleaner grit removed.

d. Sedimentation.—An improvement in both the removal of suspended solids and B.O.D. by the settling tanks was observed during 1938 as follows:

Suspended Solids:

1937—Influent 178 p.p.m.; Effluent 62 p.p.m.; Removal 65.2 per cent.
1938—Influent 184 p.p.m.; Effluent 61 p.p.m.; Removal 66.8 per cent.

Biochemical Oxygen Demand:

1937—Influent 193 p.p.m.; Effluent 122 p.p.m.; Removal 36.8 per cent.
1938—Influent 202 p.p.m.; Effluent 122 p.p.m.; Removal 39.2 per cent.

e. Sludge.—Concentration and Disposal.—The amount of sludge removed daily from the settling tanks for 1938 was slightly denser and of less volume than for 1937. The amount of decanted liquor increased considerably, from 24,175 gallons to 30,150 gallons daily, with the further results of reducing the daily accumulation of stored sludge for disposal at sea from 208 tons for 1937 to 185 tons for 1938. Actually, as disposed of, this latter amount became 194 tons daily, because of water added as a means of agitation of the sludge mass prior to loading.

f. Condition of Receiving Stream.—An indication of improvement as to the quantity of dissolved oxygen present in the receiving stream was noted during 1938. Where, during previous samplings prior to the operation of the plant, complete absence of oxygen was noted, no samples during 1938 were depleted, and the amount of oxygen present averaged on a yearly basis, 4.64 p.p.m.

The Screening Problem

The handling of screenings during the early days of plant operation was difficult and unsatisfactory. The method provided consisted of merely depositing them as fill upon the adjacent meadowland. It was impossible to bury them because the surface of the ground was under water at high tide twice a day, and nearly impossible to cover them with earth because of scarcity of material for cover and the absence of roadways over which the borrowed earth might be transported.

For nearly a year screenings were so disposed of, under the handicaps of unpleasant working conditions arising from the necessity of having to alter the positions of the discharge piping, and the presence of a profusion of rats and flies—not to mention odors.

Investigations as to a suitable method to overcome the difficulties with the screenings, above related, were made and finally resolved into

the plan to grind the screenings and return them to the incoming sewage, eventually to be deposited with the sludge in the settling tanks and disposed of with it.

Excepting during the height of a storm, when abnormal quantities of screenings may be washed down into the plant, which contain certain objects particularly of metal or stone which might tend to injure the machine when there is but little time to inspect it, all screenings produced by the plant are disposed of by grinding. During the time in which the machine has operated no mechanical difficulties whatsoever have been noted, and the operating force is highly pleased with the solution of what was the most disagreeable job in the plant.

The Sludge Problem

The operation of the settling tanks with the subsequent collection of raw sludge and removal to storage has been satisfactorily worked out into a routine matter by the past two years of experience. With the exception of certain mechanical difficulties with the plunger type pumps such as the replacement of ball valves, eccentric straps, a piston and a set of gears, the pumping of an average of 72,608 gallons of sludge daily for the past year has been accomplished without difficulty.

The concentration of the stored sludge from its original average moisture content of 94.52 per cent down to about 92 per cent or even lower is in like manner accomplished without difficulty, by controlled decantation.

The removal of stored sludge from the storage tanks to the barge for final disposal however still offers difficulty and continues to challenge the efforts of the operating force who seek the solution.

There are certain characteristics of the sludge which have been observed at the plant, which apparently explain why certain difficulties have resulted in the pumping operations to date. These have to do with the physical properties of the sludge, and as to cause, effect and probable remedy for certain of them the following notes are made:

Raw sludge as removed from settling tanks is quite uniform in consistency regardless of the amount of solids present, and its fluid characteristics in relation to similar heavy liquids are such that gravity flow through adequate sized pipes is possible. Our experience has been such that we believe freshly collected sludge of any moisture content down to say 93 per cent can readily be handled in large volumes by suitable centrifugal pumps.

When sludge is placed into storage or any container wherein the mass remains quiet for a number of hours a separation of a certain amount of the moisture present occurs. This we have called the "stratification" of the sludge and the water so separated does not readily again mix with the sludge unless they are stirred up together. By careful control this excess of water can be drawn off by decantation and the remaining sludge becomes thicker, or of lower moisture content, according to the amount of decanted liquor removed.

It is also noted that the condensed sludge acquires a jelly-like character or set, and thereafter resists efforts to cause it to flow by gravity in pipes. When trying to pump such material with centrifugal pumps difficulty from cavitation results from trying to draw in by suction the jelly-like sludge. Whether or not the stratified water originally present is allowed to remain does not materially affect the problem, for what happens is that the water is quickly pumped off leaving the heavy sludge still remaining.

At Elizabeth, sludge of 92 per cent is pumped to the barges by centrifugal pumps only by the help afforded in agitation by fire hose, reintroducing water at about 50 lbs. sq. in. pressure. Plans are now being prepared for mechanical mixing along the idea of a straight line collector, by which, it is hoped to secure better mixing and to practically eliminate the quantity of water necessary to be added otherwise.

A second important characteristic affecting pumping has to do with the viscosity of the sludge in relation to temperature. The records of two years of operation show a range in temperature of the sludge of from 48° F. to 74° F. and in times required for loading of 3500 tons from 12 hours to 4 hours accordingly.

As an indication of the effects of temperature we have noted that when 70° F. temperature prevails, high rates of pumping are obtained with total heads of around 12 ft. whereas at 50° F. heads of over 40 ft. are registered and pumping proceeds with difficulty, frequently interrupted by the necessity of shutting off the pumps and blowing out the pipe lines to the barge with compressed air, which has registered as high as 30 lbs. sq. in.

Many improvements have been made during the year in the pumping facilities such as the provision of large suction lines, quick cleanout arrangements, increased horsepower and auxiliary piping for more flexible operation. Additional improvements consisting of the substitution of a 300 g.p.m. 10 in. pump in place of the 2000 g.p.m. 8 in. pump are shortly to be made from which still greater improvement in pumping is anticipated over that already realized by the changes before mentioned.

The disposal of sludge at sea still continues to be the best and most economical method available for the complete disposal of sludge from our plant. Even with the handicaps of loading and the introduction of a certain amount of additional water, the cost of disposal of sludge is only 30.5 cents a ton, much less than possible by any other known method available to us.

Maintenance and Repair

An important part of the operation of any plant has to do with maintenance and repair. It is recognized that because of the type of material handled, gases, weather conditions and continual usage, equipment and buildings will suffer rapid deterioration unless promptly and faithfully attended to.

Considering that the plant construction was begun in 1931 and that

a considerable amount of equipment lay idle until 1937, when finally completed and placed in operation, it is indeed gratifying to be able to report that the entire plant appears today more attractive than the day operations began.

It is the policy of the operating force to practice cleanliness implicitly. All machines are thoroughly washed up at the end of the day's work, floors are scrubbed, sumps drained, tools and equipment properly stored and anything else done that may be required to keep the plant in perfect condition.

The use of paint where required to protect structures and mechanical equipment is employed as often as may be necessary. In exceptionally bad locations, where advisable or possible, non-corrosive materials such as "Everdur" are used. Where iron has been provided which now needs attention, our practice has been to galvanize wherever possible.

Mechanical and electrical equipment are subjected to frequent inspection and whatever adjustments may be advisable made. Breakdowns occurring during the year have promptly been corrected by the operating force.

Numerous improvements have been made at the plant as suggested by the plant safety committee. A few among many of these include the provision of guard rails and chains along tanks, forced draft ventilation of pipe tunnels, use of humidifiers for odor control in buildings, etc.

COST OF PLANT OPERATION—FOR THE YEAR 1938

	Amount	Percentage
Administrative and Legal	$ 5,814.15	7.24
Automotive	300.00	.37
Barging Sludge to Sea	20,603.67	25.64
Equipment, Supplies, Contingencies	2,659.19	3.31
Electric Power	2,892.16	3.60
Fuel—Oil and Gas	1,320.34	1.64
Insurance and Bonds	1,081.75	1.35
Labor, General	30,070.66	37.42
Printing and Stationery	373.02	.47
Plant Maintenance	3,286.71	4.09
Supervision, Salaries	10,239.92	12.74
Water Service	971.90	1.21
Miscellaneous	742.28	.92
	$80,355.75	100.00

The summation of cost above noted covers the calendar year of 1938.

The average amount of sewage handled daily was 26.28 million gallons from an estimated contributing population of 300,000. On the basis of the above figures the 1938 itemized costs are as follows:

Costs of Treatment per m.g.	$8.38
Cost per capita per year	.268

This shows a reduction in the cost per million gallons over 1937 from $10.97 to $8.38.

SUMMARY

Results of operation of the system for the period covered by this report indicate that:

1. Plant performance has been at all times satisfactory.

2. The Elizabeth River has continued to show improved quality due to reduction of pollution, and the condition of Arthur Kill (the receiving stream) has shown still further improvement from the standpoint of dissolved oxygen present. (4.65 p.p.m. for the year.)

3. Costs of treatment have shown a considerable reduction over those obtained during the previous year. It may be noted that $15,000 was saved out of the amount appropriated for the year and returned to the participating municipalities toward payment of the 1939 budget.

4. Operating results obtained during the year have further demonstrated the ability of the plant to take care of the increased flow which will be felt when Elizabeth is connected. Available room is also sufficient to take care of the possible contributions of Roselle and Linden when and if they should decide to participate in the treatment facilities.

5. Improvement in mechanical operation has been noteworthy:

a. Elimination of discharge of screenings to the adjacent meadowland by the installation and operation of a screenings grinder for macerating and returning the screenings to the sewage flow.

b. Improvement of sludge pumping facilities by the inclusion of quick cleanout arrangements, larger suction lines and larger motors.

c. Reduction of noticeable odor around plant by installation of forced draft ventilators.

Respectfully submitted,

LESLIE E. WEST,
Chief Engineer

SLUDGE GAS ENGINE OPERATION AT MICHIGAN CITY, INDIANA *

BY H. H. JONES *

Supt., Michigan City Sewage Treatment Plant

(While it is a bit early to arrive at definite conclusions concerning operating possibilities using sludge gas engines at this plant, a few observations taken from the daily operation sheets are herewith presented in order that "doubting Thomases," dissenters and hecklers may have an opportunity to say, "I told you so," "Baloney," etc., in case the data is not verified by later observations.—Author.)

The engine operating at Michigan City, Indiana, is a Climax "Blue Streak," No. R61, four cycle, horizontal shaft, six cylinder, valve-in-head type. The cylinders are 6×7 inches; engine rating 74 HP. at 710 R.P.M. and 100 HP. at 960 R.P.M. and 70 lb. B.M.E.P. It was built

* From "Sewage Gas," Bureau of San. Eng., Indiana State Board of Health, Sept., 1939.

to operate continuously on natural gas (1100 B.t.u.) as a heavy duty engine, at speeds varying from 500 to 1200 R.P.M. To date it has been operated on sludge gas (600 B.t.u.) at speeds varying from 525 to 870 R.P.M. It drives a Roots-Connersville blower through a 1.5 to 1 I.X.L. helical reduction gear.

The Roots-Connersville blower is a heavy duty machine having a guaranteed output of 2880 cu. ft. per minute at 710 R.P.M. and 9.2 lb. gauge pressure. Since operation at this plant is between the speeds of 350 R.P.M. (525 Engine) and 580 R.P.M. (870 Engine) working against a gauge pressure of 7.2 to 7.5 lbs. per sq. in., observations between these speeds only, are presented.

The following tabulation of operating results is taken from daily operation data and is liable to errors in gauge readings, revolution counter readings, gas intake manifold pressure variation, meter readings, and errors in computation:

Engine Speed R.P.M.	Blower Discharge Pressure	B.H.P.H. to Blower Shaft	Cu. Ft. Gas per Hour	Cu. Ft. Gas per B.H.P.H.	B.t.u. per B.H.P.H.	Gas-Air Ratio Cu. Ft.
525	7.2	49.6	968	19.5	11,700	1 : 79.5
550	7.4	53.9	978	18.2	11,000	1 : 83.3
575	7.4	56.2	1020	18.2	10,900	1 : 84.4
600	7.4	59.0	1054	17.9	10,730	1 : 85.9
625	7.3	62.7	1126	17.9	10,770	1 : 84.8
644	7.4	64.1	1147	17.9	10,730	1 : 86.1
676	7.5	69.3	1212	17.5	10,500	1 : 86.3
702	7.4	71.7	1244	17.4	10,420	1 : 87.7
730	7.4	75.6	1304	17.3	10,320	1 : 87.7
748	7.4	77.3	1339	17.3	10,390	1 : 88.0
774	7.5	80.8	1414	17.5	10,370	1 : 86.5
870	7.4	89.4	1543	17.3	10,350	1 : 91.4

The above are simple averages for from 6 to 12 days operation at the noted speeds.

Figures for B.H.P. to blower shaft are derived from the formula

$$\text{B.H.P.} = .0053 \times \text{cu. ft. air per min.} \times \text{gauge pressure.}$$

The formula and factor .0053 are used by permission of a representative of the blower manufacturer. Cu. ft. of air per min. is derived by multiplying the displacement of the blower by R.P.M. and correcting for "slip."

Cu. ft. of gas per B.H.P.H. is obtained by dividing the cu. ft. of gas used by the B.H.P. delivered to the blower shaft.

B.t.u. per B.H.P.H. is based on the assumption that gas used had a 600 B.t.u. value. Analyses from time to time of gas produced at this plant showed a "low" heat value of 580 to 620 B.t.u. per cu. ft.

The gas-air ratio is the number of cu. ft. of "free" air (30 in. of mercury pressure and 60° F. temp.) compressed by 1 cu. ft. of gas used. This figure is in error since the gas volume was not corrected for barometer and temperature.

The actual B.H.P. developed by the engine was probably 3 per cent to 5 per cent higher than indicated in the tabulation due to transmission loss in the gear reduction.

When the engine was started it was hoped that all air needed for aeration could be supplied by the gas engine driven blower. On February 22, 1939, the electric motor driven blower was stopped and the engine driven blower relied on for air. Everything proceeded normally through March, April and May until June 20 when the plant was deluged by fuel oil from a broken fuel line at one of the large factories located here. This resulted in the destruction of the aerobic bacteria in the activated sludge and affected the primary plant to such an extent that gas production dropped to one-half normal. Consequently, it was necessary to start the electric motor driven blower in order to build up a new sludge.

During the course of the above noted run, the engine was shut down every two weeks for several hours to change oil and service generally. At one period the engine was operated continuously for 60 days without a shut-down to see if the engine and gas supply could "take it." It could.

Since air requirements at this plant seem to be greater when the incoming sewage reaches a temperature of 70° F., there is still some doubt as to the possibility of supplying all air necessary with gas driven power.

It is hoped that next summer no such catastrophe as marred this year's effort will occur, and that we may have the answer then.

SMALL PLANT OPERATORS' CLINIC

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Meeting in Chicago, October 12, 1939

The "Small Plant Operators' Clinic" on the afternoon of the first day attracted about fifty persons from both large and small plants. Chairman E. J. Beatty, Assistant Engineer, Wisconsin Board of Health, called on G. C. Martin of Green Bay, Wisconsin to open a discussion on plant maintenance. The difficulties encountered with corrosion of metal and deterioration of paint in housed-in units as the result of moisture and gases were outlined. It appeared that although 200 to 300 paints from over fifty manufacturers were used none was entirely satisfactory under the conditions existing at Green Bay. Aluminum paint was found to crumble if not applied correctly, and hot-dipped galvanizing, stainless steel, and aluminum metals were found to be fairly durable. Copper screening lasted about six months. Truss members, window sash, and louvres were particularly in need of protective covering. Failures due to improper lubrication of machinery were eliminated after adoption of a greasing schedule and placing responsibility for care of units. Experiments on various packings and

sleeves led to the adoption of a uniformly hardened steel sleeve for all pumps.

C. A. Wahlstrom, LaCrosse, Wisconsin, described the means by which local assistance has been obtained to furnish materials for plant beautification. Wood benches, a flag pole, bird houses, vases, a drinking fountain, lily pond, flag stone walk, and several varieties of trees were among the items donated for use in plant beautification. As a result of the beautification the plant grounds have become the "mecca" of local civic clubs which, incidentally, also inspect the treatment works.

Chairman Beatty opened the discussion on high- and low-rate filters with especial reference to the desirability of effluent recirculation. Math Fisher, West Bend, Minnesota, disagreed with effectiveness of recirculation as he found that filter flies were killed by dosages of chlorine and they did not recur until recirculation was resumed. He suggested that perhaps larvae were returned to the filter by the effluent. Painting oil and kerosene on the filter walls has helped reduce fly numbers. T. J. Burrin, Kokomo, Indiana, reported that flushing filter walls by streams of water from holes in ends of rotary distributor prevented fly breeding.

J. E. Hupp, La Porte, Indiana, stated that a filter clogged by a wool fiber was corrected by heavy chlorination. Chairman Beatty asked for a suggestion for removing pine needles already in a filter, without success. J. W. Nadin, Paris, Illinois, reported on operation of a high-rate filter with special reference to forced draft during periods of high air temperatures and low sewage flows. H. G. Rogers supplemented the high-rate discussion with his observations of flocculent suspended solids in the secondary tank, and use of tile and rock media. Continuous high-rate dosage prevented formation of flies.

In a discussion of activated sludge it was generally agreed that the proper amount of mixed liquor suspended solids depended upon so many factors that it presented a different problem for each plant. Don Bloodgood, Indianapolis, W. E. Ross, Richmond, Indiana, J. C. Mackin, and C. N. Sawyer, Madison, Wisconsin, gave interesting viewpoints as to the mechanism of activated sludges in various concentrations. R. Dick, Jr., Elmhurst, Illinois, reported bulking both with high solids content and after rains. A discussion of over-aeration indicated that while ordinarily the plant design does not permit over-aeration it is possible to reduce the activity of the sludge by an abundant source of air and produce a granular material having a low index, rapid settleability, and causing "feathers" or scums in the secondary settling tank. Bulking troubles have been reduced and an economy in air consumption effected by use of a biometer at Richmond, Indiana, according to W. E. Ross. C. N. Sawyer reported gaseous nitrogen formation and rising sludge coincidental with nitrification and oxidation reactions, nitrification occurring because of lack of food in sludge.

A discussion of supernatant return brought out the fact that this feature is particularly important in plants employing the activated sludge process. H. H. Jones, Michigan City, found that no bulking has

occurred since aerating supernatant for 20 hours (between supernating periods) before return to raw sewage. One trial aeration of supernatant with added activated sludge was not successful.

Ross, Richmond, Indiana and R. H. Corr, Woodstock, Illinois, reported markedly increased gasification and turbid supernatant with direct addition of waste activated sludge to the digester. C. O. Baetz, Appleton, Wisconsin described how increasing pressure in digester after temperature drop caused scum to disappear although increased gasification may have been responsible. Good sludge drying and low volatile content after "3-stage digestion," was reported.

A short discussion on garbage digestion brought out the fact that this material having higher volatile matter resulted in an increased amount of gas.

Dr. Mohlman of the Chicago Sanitary District and Miss Gladys Swope of Waukegan, reported that the slight reduction in suspended solids and B.O.D. obtained by short preaeration of sewage without addition of chemicals was not significant. However, Bloodgood reported 75–80 per cent and 85 per cent B.O.D. reduction and suspended solids removal respectively by plain aeration of sewage for 4½ to 5 hours.

An attempt to treat sulfite waste at Green Bay, Wisconsin, was an interesting one according to G. C. Martin for it produced slime in clarifiers, and generated a gas having as high as 300 grains of hydrogen sulfide per 100 cu. ft. Since 150 gr. per 100 cu. ft. was considered as high as permissable for use in the gas engine, the waste was cut off. The experiment did show, however, that the material when taken out of the river did result in temporary lack of objectionable pollution. It was only because of a succeeding paper that it was necessary to curtail an interesting discussion of industrial waste problems.

Notes by Richard S. Nelle,
Assistant Sanitary Engineer,
Illinois State Department of Public Health

EXCERPTS FROM "MINNEAPOLIS–ST. PAUL SANITARY DISTRICT REPORT FOR 1938"

By George J. Schroepfer, *Chief Engineer*

Operation of Plant Started.—Shortly after dedication of the treatment plant on May 16, 1938, preliminary operation and testing of the equipment in the plant was begun. On June 1 the first sewage was turned into the intercepting sewers and into the plant.

The treatment plant itself was placed in operation under a planned and definite schedule which called for a gradual starting of the various units. The plant is divided into two separately operative halves or batteries which can be operated independently of each other. Advantage was taken of this fact in starting the plant.

Operation of the various units was begun without difficulty except as might be expected with mechanical equipment of the type required

in a large plant. The manufacturers of the magnetite effluent filters and the incinerators experienced the greatest difficulties in placing their equipment in satisfactory operation, some of which are discussed in more detail later.

Continuous 24-hour operation of the plant was begun on July 20. From then on all the equipment which had been accepted by the District performed in an acceptable manner. However, because of the manufacturer's difficulties with the incinerators it was necessary to by-pass varying quantities of sewage from time to time, depending on the amount of sludge which could be incinerated. After October 3 no sewage was by-passed at the plant with the exception of excess storm flows, the excess sludge which could not be handled by the incinerators being pumped directly to the river. It was not until the latter part of November that the incinerators were capable of incinerating all the sludge produced at the plant.

Screen and Grit Chambers.—Sewage was first taken through the screen and grit chambers on June 1. During the first seven months of operation to December 31 a total of 15,619 cu. ft. of screenings and 91,769 cu. ft. of grit was removed by the screen and grit chambers. This amounts to an average of 1.05 cu. ft. of screenings and 6.2 cu. ft. of grit per million gallons of sewage treated. Based on a study of 117 screen installations throughout the country the average quantity of screenings removed by screens with 1 in. openings was 3.1 cu. ft. per million gallons. The quantity of screenings produced by the Twin City plant fortunately was only about one-third of the quantity which might have been expected. On the other hand, the quantity of grit was somewhat greater than was expected. An average of a number of plants in this country is 4.1 cu. ft. per million gallons.

Because of the small quantity of screenings in comparison to grit it was possible to bury the screenings with grit. Shredders were used only to test out the equipment and periodically to keep the equipment in satisfactory operating condition. A variety of material was removed on the hand-raked coarse bar racks (6 in. openings) at entrance to the plant. Material removed at this point has ranged from logs and timbers, whole trees, to cattle paunches. The discharge of cattle paunches was obligingly discontinued by the industry after this condition was called to its attention.

An unusually clean grit was produced by the grit chambers, averaging 6.6 per cent volatile solids. The moisture content of the grit averaged 20.1 per cent. The screenings contained an average of 81.9 per cent water and 78.0 per cent volatile solids.

Settling Tanks.—From the time the settling tanks were placed in operation on June 9 they operated continuously and satisfactorily. The removals accomplished by the settling tanks were unusually high, both from the standpoint of those expected, and from a comparison with the removals by other primary settling tanks throughout the country. The fact that the tanks operated satisfactorily, both from the viewpoint of reliability of equipment, and efficiency of removals, is

gratifying when consideration is given to the fact that the long tanks represent some degree of departure from precedent, both for the purpose of effecting constructive economies as well as to accomplish the higher removals expected from a consideration of a number of theoretical factors.

The average removals by the settling tanks since 24-hour operation began on July 20 was 68.8 per cent of the suspended solids and 36.0 per cent of the 5-day B.O.D. The average detention period was 2.15 hours. However, for various reasons, chiefly associated with early difficulties in incinerator operation, the number of settling tanks in use varied quite widely from month to month and within each month. For this reason, operation during the month of December is more representative of actual plant performance. During this month the average removals of suspended solids was 73.0 per cent and of 5-day B.O.D. 44.7 per cent, with raw sewage strengths of 255 p.p.m. and 245 p.p.m., respectively. The average detention period was 3.5 hours. This compares with expected removals for a detention period of approximately 2½ hours, of 56 per cent of the suspended solids and 36 per cent of the 5-day B.O.D.

A number of improvements were made in the appurtenances to the settling tanks to increase dependability and to simplify operation. Perhaps of most importance is the method of handling scum after its removal from the settling tanks. Automatic skimming mechanisms remove the material from the settling tanks and deposit it in scum troughs from which, with some flushing, it is transported to scum manholes. In the original installation scum was discharged from this manhole to a sump from which the suction of duplex 200 g.p.m. scum pumps was drawn. Difficulties were encountered early because of segregation of materials in this sump and in an effort to correct this condition the suction was connected directly to the pumps. However, suction and discharge lines as well as the pumps themselves became plugged frequently, and in addition to using enormous quantities of transporting water it was necessary to screen out all material retained on three-quarter inch racks. In spite of this, after four months of operation, the scum discharge line cross sectional area has been reduced to one-tenth of its original area by grease incrustations. A number of different methods of handling were considered, of which an ejection method was selected chiefly because of its possibilities of handling relatively dry scum, which is an important consideration in connection with final disposal. This method was installed with the result that dry material could be handled without the necessity of removing large material and without attendant plug-ups, which greatly simplified disposal problems. While this problem may appear unimportant from the standpoint of general plant performance, it has greatly reduced the amount of labor required in this portion of the treatment process.

No difficulties were experienced with freezing of sewage in the settling tanks or effluent filters during the winter months. Even with temperatures as low as 25 degrees below zero, sewage temperatures

dropped only about 4 degrees Fahrenheit through the plant. Some difficulty was experienced with the automatic skimming mechanisms during cold weather. Heavy frost gathered on moving parts of the equipment with the result that some attachment links were broken. It was found much more economical under these conditions to skim the material into the scum trough by hand, than to attempt to keep the equipment operating.

Effluent Filters.—The downward flow magnetite filters were first placed in operation July 6. This equipment was purchased under guarantees providing for removals of suspended solids, as follows:

Influent Strength, P.p.m.	Reduction Through Filters, P.p.m.
30	2
50	9
70	18
90	29
110	40
130	50

The filters were designed for an average rate of 3 gallons per sq. ft. per min. and a short time maximum rate of 6 gallons. This compares with average rates at other plants of 2 to 2.5 gal. per sq. ft. per minute.

Early operation of the filters indicated that the filters would meet the guaranteed removals but at flows greater than the average, difficulties with sand erosion occurred. This was chiefly a hydraulics problem associated with the size of the influent ports and otherwise with facilities for introducing sewage to the beds. As a means of correcting some of these difficulties the manufacturers doubled the area of the influent ports and at the close of the year were installing baffles in these ports to properly direct the flow into the beds.

Note: For sludge disposal data, see article on "Sludge Disposal at the Minn.-St. Paul Plant," in this issue.

Operation Costs.—The cost of operation during 1938 was considerably less than originally estimated. When the budget for operations was first adopted in June, 1937, the costs for the period May 1, 1938, through December 31, 1938, were estimated as shown in the following tabulation. For various reasons, chiefly associated with delays in completion of one intercepting sewer contract, the plant was not started on May 1st. A revised budget was adopted on July 1 covering the period from June 1 to December 31, 1938, and providing for reductions in the budget of some magnitude. The estimated requirements in the original revised budget were as follows:

	Original Budget	Revised Budget
(a) Material and Supplies	$149,405.00	$ 85,615.00
(b) Repairs, Replacements and Renewals	41,999.00	32,780.00
(c) Power and Light	35,556.00	26,940.00
(d) Miscellaneous	13,195.00	11,093.00
(e) Labor and Supervision	106,819.00	83,669.93
TOTAL	$346,974.00	$240,097.93

It will be seen that this revised budget provided for a reduction of somewhat over $106,000.00. The actual expenditures during the period from June 1 to December 31 were $157,868.13, divided as shown in the financial report which is included as Appendix B. The actual expenditures were $189,105.87 under the original budget estimate, and $82,229.80 under the revised budget estimate. Some of the saving over the budget estimates resulted from less complete operation of the plant in the early months than was estimated (which, however, provided for partial operation during the first two or three months) caused by the manufacturers' difficulties with the incinerators. A very substantial portion of the savings resulted, however, from economies effected in the operation of the plant. The budget estimates were founded on experience in other plants throughout the country, adjusted to our particular requirements.

Laboratory Work in 1938.—The laboratory work in 1938 included a record of Mississippi River conditions, studies on certain industrial wastes, some experimental work on chemical treatment of sewage, tests on paints and chemicals used in the treatment plant, and the routine analytical data on plant operation since treatment of the sewage was begun in June.

River water samples were collected at twenty-seven stations established on the Mississippi and its tributaries between Minneapolis and the outlet of Lake Pepin, a 95-mile stretch covering the zone which has been affected by sewage pollution from the Twin Cities.

The work on industrial wastes was done for the purpose of assisting industries in separating clean water from contaminated water in connection with the application of the Minneapolis sewer rental ordinance.

Since the treatment plant was placed in operation, twenty-four hour composite samples have been collected of the sewage in the various stages of treatment, screenings and grit, sludge, filter cake, incinerator ash, and return liquors such as the sludge supernatant and filtrate. The results of the analyses of these samples are used to interpret the efficiency of the plant under various conditions of operation, and serve as a basis for proper control and improvements in the operation of the plant.

General.—The sewage flow arriving at the plant was less than the estimated flow of 120 m.g.d. for the year 1938, averaging somewhat under 100 m.g.d. Most of this difference is explained by the fact that all sewer connections had not as yet been made, as well as because of curtailed industrial activity. The strength of the incoming sewage, however, was somewhat greater than was anticipated, averaging 240 p.p.m. suspended solids basis, and 200 p.p.m. 5-day B.O.D. This compares with expected strengths of 185 p.p.m. and 200 p.p.m., respectively. The increased strength placed a greater load on the treatment plant, especially on the sludge disposal processes, than was anticipated.

By the fall of 1939 landscaping work had been completed, the plant presenting a formal appearance consistent with its service. It is planned to plant several gardens during the spring of 1939. A con-

sistent effort has been made to keep the buildings and grounds clean and orderly. Furthermore, the staff has been careful and conscientious in keeping the plant free from odors with effective results. While sewage and sludge odors are necessarily present in certain of the buildings, these have been held to a minimum, and their effect has been limited to the plant grounds.

Reports of operations are prepared and presented to the Board of Trustees monthly. These are in greater detail than it is possible to present in an annual report. These reports are submitted to the State Board of Health and are available to the public.

With the large amount of equipment in a modern sewage treatment plant, some of which has been used only a few years, the process of placing a large plant in operation is rather involved, especially from a mechanical standpoint. The Sanitary District wishes to record with satisfaction the fine cooperation accorded by manufacturers of various equipment. It is gratifying to note that while extensive guarantee and maintenance bonds of various types were provided for in the mechanical contracts, it has not as yet been necessary to invoke any of their compliance provisions.

EXTRACTS FROM FIRST ANNUAL REPORT OF THE BUFFALO SEWER AUTHORITY—1938–1939

Sewage Treatment Works

By Charles R. Velzy, *Works Superintendent*

On June 18, 1938, the intercepting chamber at Bird Avenue and Niagara Street was opened and sewage at the rate of about 20 m.g.d. was turned into the interceptor and pumped at the plant. Following that date additional intercepting chambers were opened until, by July 1, 1938, the flow from the entire sewer system of the City of Buffalo was being received, pumped and treated at the treatment works.

Notes on Operation

Pumping.—During the first two months of operation, the manufacturers' representatives checked the main pumps and auxiliary equipment with a view to determining what adjustments would be essential. It was found that the pumps discharged at a rate appreciably above the specified rate and it was therefore decided that the impellers should be cut down. During the same period adjustments were made on the discharge valves and on other parts of the auxiliary equipment.

During February and March the acceptance tests were run on all pumps. This was accomplished during the normal operation of the plant by taking one pump at a time and selecting periods when rates of flow suitable for pump testing could be obtained. All pumps were found to be satisfactory and to meet specifications and guarantees.

During the year one storm in September, 1938, required the use of five pumps. One other storm in the Spring of 1939 required the use

of four pumps for several hours. Other than on these two cases storm flows have been handled by not more than three pumps. The pumping station has always been capable of handling the entire flow received at the Treatment Works.

Screening and Grit Removal.—During the first few months of operation there were removed by the screens large quantities of screenings, together with coarse gravel, brick bats and the like. This caused some overloading and jamming of the screens and rakes resulting in breaking of shear pins but no permanent damage. In the first few weeks of operation abnormal quantities of grit and water logged semi-fibrous material were settled out in the grit chambers, overloading the grit machines and greatly increasing the labor required in this department. The abnormal quantities and unusual characteristics of screenings and grit first received were apparently due to the flushing of old sewers when the interceptor was placed in operation.

Sedimentation.—Settling tanks and their mechanisms were completed some time before operation started. Their operation has proceeded normally and practically without difficulty with the exception of two breakdowns early in the year. These interruptions were due to damages to the mechanisms when one of the skimmers was caught in breaks in the welded joints on the baffle plates in the tanks. These repairs having been made, no further difficulties were encountered in the tank operation. Removal of scum from the tanks and its disposal has been somewhat of a problem during the first year. Studies have been made and adjustments are under way to improve this process.

Sludge Tanks.—The storing of raw sludge in the sludge tanks started with the beginning of operation. It was obvious that attention would have to be given to the handling of the sludge in order to control so far as possible the reactions incident to starting of the sludge tanks. Three of the four tanks were used first, the fourth one being held for storage of sludge during such period as foaming might occur in the first three. During the month of August first evidence of foaming was observed. Lime was added and pumping of raw sludge was diverted from the first three tanks to the fourth tank. Foaming continued into the month of September. After several weeks, it subsided and has not recurred. Later on the fourth tank was emptied of raw sludge and started without foaming by the use of active sludge from the other three tanks.

The operation of the sludge tanks since September, 1938, has been normal with the exception of the use of one of the tanks for a short period during the spring to store raw sludge for the incinerator tests. This tank was taken out of regular service for this purpose and returned to normal use with only a slight indication of foaming which was under control at all times.

Sludge Disposal.—The operations of sludge dewatering and incineration were not required when the plant first started because of the need of filling the sludge tanks first with raw sludge. The vacuum filters and incinerators were started during the month of August. They

were operated for about two months for the purpose of tuning up the equipment and making necessary adjustments. During the first half of November, 1938, a satisfactory acceptance test was made on the vacuum filters.

During the first few months of operation, two major problems developed. One was the synchronizing of filter and furnace operation; the second one related to the handling of the ash from the furnaces.

It was found that sludge could be filtered at considerably higher rates than was specified or expected. Filters were designed to discharge 100 tons of sludge cake a day having a moisture content of 70 per cent. It was found that they would discharge about 200 tons per day of sludge cake having a moisture content approaching 60 per cent. Operation thus far indicates that this was accomplished with the normal use of chemicals. Under these conditions it has been difficult to keep the rate of production of filter cake low enough to successfully operate one incinerator. In part to overcome this problem and in part to produce a more uniform spreading of the cake on conveyor belts, attention has been given to the development of a sludge cake feeder, to receive the cake from the filter and discharge it on to the conveyor belts at a uniform rate. In January, 1939, a trip was made to Auburn, New York, to inspect the operation of a screw type feeder which might apply to our filter. Subsequently a feeder of this type was ordered and furnished by the contractor and has been in use for several months with encouraging results. Improvements on this feeder are contemplated, and eventually a feeder for each filter will be installed.

The problem in the handling of ash resulted from the fact that the ash comes from the furnace at a higher temperature than was contemplated. The original installation of pneumatic equipment included bag filters to prevent the discharge of dust from the ash handling equipment. It was found that these bags burned out as a result of these high temperatures. The contractor has, therefore, installed a new ash handling system, including mechanical separators instead of filter bags and a steam ejector in place of the original vacuum pump. This was done after careful consideration of steam consumption on the part of the engineers. This system has operated satisfactorily.

During the first few months the incinerators were operated under the direction of the manufacturer's representative. Between the months of October 1938 and January 1939 the incinerators were subjected to the specified 60 day acceptance tests, and in May 1939 the specified 24 hour tests were run on each furnace. At the end of the year, the contractor is making the adjustments indicated by the tests and the first year of operation.

Laboratory

Report by G. E. Symons, *Chief Chemist*

For the first seven months of the year the Bird Island Laboratory staff was housed in crowded quarters in the Customs Building. The

last five months of the year were spent in organizing and equipping the new quarters. Regular hourly sampling was not put in practice until late in July. Two changes in personnel occurred in the fall of 1938. In November special work in connection with the testing of incineration equipment was assigned to the Laboratory. An extra chemist employed under construction performed the work. At the end of the year the effect of these extraneous factors had been overcome to the extent that a complete operating routine had been established.

Special Laboratory Work

Boundary Water Studies.—These were confined to monthly surveys of the Buffalo and Niagara River and some sampling of Park Lane. As has been the practice, these data will be reported in an annual summary. In general, it may be said that with the removal of sewage from the Buffalo River, its septic and bacteriological condition was improved. However, since the industrial wastes have not all been removed, the appearance of the stream has changed little in the past year.

Great improvement was apparent in the Niagara River. Bacterial tests indicated that following sewage treatment, the bacterial content of the River was reduced to approximately 3 per cent of what it had been in the two previous years. The waters of Black Rock Canal also showed immediate improvement after sewage treatment was inaugurated.

Research Studies.—There was little fundamental research done in the laboratory on the problems in this class. This was due to lack of equipment in the temporary quarters and to lack of time while equipping the permanent laboratories. However, routine data which were collected will be utilized as research data and tabulated and compiled into reports on the various studies involved.

For example, the hourly and daily chlorine demand, and the relation between bacterial kill, percent satisfaction and contact time will all be subjected to statistical study. The ultimate purpose of these studies will be to determine the proper control of chlorine dosage to obtain the desired results at least cost.

Daily data were collected on different methods of determining suspended solids in sewage, in an effort to develop better control and analytical methods.

Some special work was directed to the study of sedimentation in the clarifiers and the proper location of sampling stations. Special analyses of sludge were made to determine fertilizer value. The study of sludge conditioning and the calibration of chemical feeders also received attention. A definite program of routine has been set up for further study of this important problem.

Industrial Studies.—Practically no analytical work was done. It was reported that the Socony Vacuum Oil Co. had completed extensive changes in their oil trap which had effectively reduced their polluting wastes. It was also reported that the National Aniline and Chemical

Co. had reduced their wastes by 25 per cent and that they are continuing studies.

Operating Results

The accomplishments of the first year of operation may be expressed in a few brief statements of total quantities. There have been received, pumped, and treated 47,923 million gallons of sewage which amounts to an average of 129.7 m.g.d. or 216 gallons per capita per day. From this sewage there has been removed solid material which, if dried, would amount to 16,000 tons. This solid material, most of which is known as sludge, has produced in the sludge disposal process, about 116,000,000 cu. ft. of combustible gas which has been used in the heating plant of the treatment works. The rest of the sludge has been incinerated, leaving a residue of about 4,000 tons of ash.

Quantities of Sewage.—The monthly averages show a consistently higher rate during the winter months. With the exception of August, 1938, when there were several relatively heavy storms, the summer months show averages below 110 m.g.d. The daily records show the dry weather flow to be consistently between 100 and 110 m.g.d. with a few days below 100 m.g.d. The maximum rate during the year was 560 m.g.d. and the maximum flow for one day was 333.9 million gallons.

Characteristics of Sewage.—The characteristics of the raw sewage as measured by suspended solids, B.O.D., and chlorine demand have been reasonably consistent throughout the year. The suspended solids as expressed in pounds per capita per day appear exceptionally consistent except for October which is high and January which is low. During the latter part of October the method of sampling raw sewage was apparently in error. When a correction is made for this error the suspended solids are estimated to amount to about 0.36 pounds per capita per day with corresponding changes in the other data.

Removal of Suspended Solids.—The removal of suspended solids has been about normal except for the months of February, March and April when flows were considerably above the average. The lower removals during the higher flows led to studies in April of settling tank action. Further studies are to be made which it is expected will point to some adjustments in the baffling arrangement to improve the removal particularly for higher flows.

During October and November and again in May and June the supernatant from the sludge tanks was heavy due to interruptions in sludge disposal operations. This has affected removals in the settling tanks and accounts for the large differences during these periods between over all removal and tank removal.

Chlorination.—Routine records of chlorination have been kept since September, 1938. The average use of 4,880 pounds per day has been somewhat below the estimated requirements, but the kill of *B. coli* organisms has averaged almost 99 per cent and has been consistent.

Sludge Disposal.—Sludge disposal operations have been under a handicap throughout the year because of equipment testing and the

adjustments incident to placing the plant in operation. The dewatering by filters has been above the guarantees in rate and the average moisture content of 61.8 per cent is better than was anticipated. The problem of synchronizing the high filter rate with normal incinerator rate has been in part solved by installation of a feeder mechanism at the discharge of one of the filters.

A rough solids balance for the sludge tanks is as follows:

Dry solids removed from raw sewage, not including grit		26,233,300
Solids burned (corrected for chemicals)	11,826,000	
Solids converted into gas (at 15 cu. ft. per lb. vol. solids digested)	7,726,600	
Sludge inventory July 1, 1939	6,390,500	
Unaccounted for	290,200	
	26,233,300	26,233,300

The difference of 290,200 pounds represents a lack of balance between material entering the tanks and material leaving the tanks amounting to 1.10 per cent.

These figures, however, cannot be considered accurate for several reasons, among which are difficulties in measuring and sampling sewage and sludge, loss of gas at the tank covers, irregularities in operation and the like.

Some further checking of data would be possible by comparisons between totals of various items or by "balance" computations similar to the above except that in several cases the records for the beginning of this first year are necessarily incomplete.

The lime used for conditioning sludge amounts to 9.25 per cent based on dry solids burned and available CaO. The amount of anhydrous ferric chloride used was 2.31 per cent of the dry solids. In both cases the small stock of chemicals on hand July 1, 1939, is ignored.

Editorial

SLUDGE DISPOSAL AT MINNEAPOLIS, BUFFALO AND CHICAGO

We are fortunate to have, in this issue, papers on the disposal of sludge by filtration and incineration at three of the most modern and largest American plants. The Minneapolis sludge disposal plant has been in operation since July, 1938, the Buffalo plant since September, 1938, and the Chicago Calumet plant since July, 1936. The new Chicago Southwest plant has been in operation only a few months and will not be receiving all sewage to be treated until the Racine Avenue Pumping Station is completed, late in 1939.

The capacities of these four plants are given as follows:

	Tons of Dry Solids per Day		Type of Sludge
	Design	Present Operation	
Minneapolis-St. Paul	180	111	Settled, raw
Buffalo	90	65	Settled, digested
Chicago Calumet	40	28	Activated + settled, raw
Chicago Southwest	375	—	Activated + settled, raw

In all plants vacuum filters are used for dewatering, followed by multiple-hearth incinerators at Minneapolis, and by flash dryers at Buffalo and Chicago. The significant differences, however, are not so much those of mechanical equipment as of type of sludge. The Minneapolis sludge is undigested settled solids, Buffalo is digested settled solids, while the Chicago sludge is mostly activated, with about one-fourth from primary settling tanks, none of it digested. There are very profound differences in the filtrability of these sludges, particularly with reference to the moisture content of the sludge drawn from the tanks, the type and amount of chemicals used for conditioning, and the moisture content of the filter cake.

One of the most characteristic properties of activated sludge is its very low content of solids, even after long settling, whereas primary sludge, raw or digested, can be concentrated, prior to filtration, to more than twice the solids content of activated sludge. This makes the problem of dewatering activated sludge much more difficult than that of dewatering primary sludge. Likewise the filter cake produced from activated sludge contains nearly three times as much water per unit of solids as the filter cake from raw or digested sludge from primary settling tanks. This means that much more heat will be required to dry activated sludge than raw or digested settled sludge. Comparisons of drying processes should therefore be based on the evaporation of equal weights of water, not on the weight of dry solids.

These facts are so well-known to all those familiar with sludge disposal that they scarcely need be mentioned, but those unfamiliar with the properties of sludge might wonder why there is such a great difference in the results from the three plants under discussion. These differences might best be shown in the form of a table, shown at top of page 1090.

The differences in moisture contents of sludge and filter cake are shown strikingly in the ratio of water to solids. Three times as much water must be evaporated at Chicago as at Buffalo, to produce one ton of dry sludge. Differences in conditioning are shown, particularly the absence of lime for treatment of activated sludge. Lime is used with raw or digested settled sludge, with ferric chloride, unless elutriation is used, in which case lime is unnecessary. Neither elutriation nor lime, however, is effective with activated sludge, which is best flocculated on the acid side, but the amount of ferric chloride needed is two or three times as great as with settled sludge. There is an advantage in the use of

Sludge Filtration

Plant	Type of Sludge	Moisture Content		Tons Water per Ton Solids		Conditioning Chemicals Per Cent of Sludge Solids	
		From Tanks	Filter Cake	Raw	Filter Cake	Lime as CaO	$FeCl_3$
		%	%				
Minneapolis	Settled, raw	90.64	64.6	9.7	1.8	7.30	2.38
Buffalo	Settled, digested	88.0	61.8	7.3	1.6	9.25	2.31
Chicago	Activated + settled, raw	97·13	82.5	33.8	4.7	0.00	7.1

ferric chloride alone, when sludge is dried for sale as fertilizer as the ash content is not increased appreciably, whereas there is a large increase when ferric chloride and lime are used.

The cost of chemicals can be estimated from the percentage used, as follows:

Cost of Chemicals for Sludge Conditioning

Plant	Cost per Ton		Cost per Ton Dry Sewage Solids			Ash, Per Ct.		Sludge
	Lime as CaO	$FeCl_3$	CaO	$FeCl_3$	Total	From Tanks	Filter Cake	
Minneapolis	$7.75	$44	$.57	$1.05	$1.62	37.8	44.0	Settled
Buffalo	9.00*	36*	.83	.83	1.66	—	61.2	Settled
Chicago	—	30	—	2.13	2.13	44.4	46.4	Activated

* Estimated.

The increase in ash content of the settled sludge is considerably greater than the increase with activated sludge. Use of lime with the latter would add more ash and thus reduce the nitrogen content, which is important from the fertilizer sales standpoint. In fact the increase in cost of chemicals of about $.50 per ton for activated sludge is probably more than recovered by the additional value of a higher content of nitrogen, when lime is not used.

The question of odors from sludge filtration and incineration are of importance. Mr. Dundas states "The successful elimination of odors proved to be a combustion problem. All the vented gases from the drying of sludge must be passed through the combustion chamber of the furnace at as high a temperature as possible, about 1100° F., in the presence of sufficient oxygen to assure complete combustion of the offending compounds." This procedure is a fundamental requirement of the flash-drying process, and therefore odors are eliminated. The use of Cottrell precipitators prevents a large loss of fly ash.

For further discussion of the two types of dryers and incinerators, see the paper by Mark Owen, "Developments in Sewage Sludge Incineration" in the January, 1938, issue and by D. C. Reybold, "Sludge Drying and Incineration" in the January, 1939, issue. These two papers, plus the three under discussion in the present issue, present a good resumé of the present status of the mechanical dewatering, drying and incineration of sewage sludge.

F. W. M.

Proceedings of Local Associations

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Twelfth Annual Meeting

Chicago, Illinois, October 12–13, 1939

The meeting was called to order at the Congress Hotel in Chicago on October 12, 1939. Total registration was 240 members and guests in addition to which there were about 25 ladies.

Opening Session

President Schroepfer presided. In the absence of Ross G. Woodhull and W. H. Trinkaus who could not attend, the address of welcome and paper on "The Sewage Treatment Program of The Sanitary District of Chicago" was presented by L. M. Johnson, Engineer of Maintenance, The Sanitary District of Chicago. About 150 were present at this session.

The report of the Secretary was read and was accepted. The Treasurer's report was received subject to the approval of the auditing committee. The following committees were appointed:

Auditing	*Resolutions*
Howard Jones, *Chairman*	C. W. Klassen, *Chairman*
H. O. Lord	C. N. Sawyer
Ben Storey	Ed. Ross
W. D. Hatfield	H. G. Rodgers

Technical Program

The "Small Plant Operator's Clinic," an innovation this year, and the "Operator's Breakfast," proved very successful; 45 being registered at the former, which was held simultaneously with the technical program, and 90 in attendance at the latter.

Papers presented at the meeting were as follows: "Filtration and Incineration at Buffalo" by C. R. Velzy and Harold Epstein; "The Flash Drying System of Sludge Disposal" by Wm. Dundas; "Sludge Disposal at Minneapolis-St. Paul" by G. J. Schroepfer; "Activated Sludge Oxidations, V. The Influence of Nutrition in Determination of Activated Sludge Characteristics" by C. N. Sawyer; "Packinghouse Wastes and Sewage Treatment at Austin, Minnesota" by Paul Hansen and K. V. Hill; "Sewage Treatment at Gary" by L. R. Howson; "Abatement of Pollution in Illinois River Valley" by C. W. Klassen; and "Operating Problems in Starting the Southwest Plant of The Sanitary District of Chicago" by L. M. Johnson, A. H. Goodman, C. T. Mickle, G. G. Poindexter and Roy Hageman.

The annual banquet which was held in the Casino Room of the Congress Hotel was addressed by Mr. Langdon Pearse, sanitary engineer of the Sanitary District of Chicago. The title of his address was "Thirty Years of Progress in Sewage Treatment by The Sanitary District of Chicago."

A very fine musical program was presented by Jenska Slebos, 'cellist, Margaret Heywood Wood, soprano, and Wanda Paul, pianist.

All sessions of the meeting were unusually well attended due to the high calibre of the program.

On Friday afternoon an inspection trip was made of the Southwest Treatment Works of the Sanitary District of Chicago.

Awards

By unanimous vote of the Executive Committee, Dr. F. W. Mohlman was awarded recognition as the Association's first Honorary Member, in view of his outstanding service to the Federation, this Association and to the profession in general.

The award for the best paper presented at the 1938 annual meeting was voted Clair N. Sawyer and M. Starr Nichols for their contribution, "Activated Sludge Oxidations. I. Effect of Sludge Concentration and Temperature on Oxygen Utilization."

Of the five gadgets entered in this competition, first prize was voted George W. Martin of Green Bay, Wisconsin for his "Hydrogen Sulfide Computator," and Mr. Martin was given possession of the plaque contributed by Dr. Mohlman in 1938, for the year 1939–40. Second prize went to Ed Ross and David Backmeyer of Richmond, Indiana for their "B. O. D. Dilution Dispenser" and third prize to P. W. Richards of Indianapolis, Indiana for his "Pump Reversal Switch."

Business Meeting

The Auditing Committee reported favorably on the report of the Treasurer and this report was regularly accepted.

The Resolutions Committee offered resolutions regarding (1) the death of E. E. Smith (2) the death of Dan Alford (3) appreciation of the fine work of Langdon Pearse as Editor of the Federation Book (4) urging enactment of the Barkley-Vinson national stream pollution control bill by Congress and (5) appreciation of the fine work of the arrangements committees in preparing for the current annual meeting. The resolutions were adopted and the Secretary ordered to send them as presented.

B. A. Poole reported verbally on the preliminary work done by the Committee on Operator's Qualifications.

The nominating committee recommended the following slate and a motion for unanimous election was regularly passed:

President—B. A. Poole
First Vice-President—C. C. Larson
Second Vice-President—G. W. Martin

Third Vice-President—K. L. Mick
Secretary-Treasurer—W. H. Wisely
Representative to Federation—W. W. DeBerard

Invitations to hold the next annual meeting at (1) Indianapolis (Don Bloodgood) (2) Fort Wayne (Mayor Harry Baals) and (3) Gary (R. Rowley) were received for consideration by the Executive Committee.

Under new business, it was regularly moved and seconded that an award in the form of a key be made each retiring president of the Association. The secretary was directed to investigate the cost and design of such an emblem and to report to the Executive Committee. An emblem would be awarded each past president also. Motion carried.

W. H. WISELY, *Secretary*

NEW ENGLAND SEWAGE WORKS ASSOCIATION

Tenth Annual Fall Meeting

Winchendon, Mass., September 29–30, 1939

The Tenth Annual Fall Meeting of the New England Sewage Works Association was held on September 29–30, 1939, at the Toy Town Tavern in Winchendon, Mass. One hundred and thirty-four members and guests, which included twenty-seven ladies, were registered for the meeting, which established an all time record for attendance at an annual meeting.

The Friday morning session was called to order at 10:00 A.M., by President F. W. Gilcreas. At the business session, a Nominating Committee consisting of Messrs. R. S. Weston, H. W. Bauer and E. C. Johnson was appointed by the President to consider a slate of officers for 1940. A change in Article VI of the Constitution was passed by the membership and which now reads:

> The Officers of this Association shall be a President, a first Vice-President, a second Vice-President, a Secretary-Treasurer, and three Directors. The term of office shall be one year. Officers shall be elected at the Annual Meeting in October to take office the following January 1st. No officer, except the Secretary-Treasurer, shall serve more than two years consecutively. The retiring President shall serve as an advisory member to the Executive Committee for a period of one year following his term of office.

The reports of the Secretary and Treasurer were read in open meeting and accepted.

The death of Mr. Christopher Hanson of Marlboro, Massachusetts, a charter member in this Association, was announced and silence was observed in his memory.

The first speaker of the morning session was Mr. J. A. Muldoon, Superintendent of Sewage Treatment, Bridgeport, Connecticut, who spoke on "Fine Screening of Sewage."

The second paper of the Technical Session, "Operating Data for the New Britain Sewage Treatment Plant" was presented by Mr. John Szymanski, superintendent of the municipal sewage treatment plant,

New Britain, Connecticut. Mr. Szymanski presented his 1938 operation report.

The third and last paper on Friday morning was given by Mr. Arthur D. Weston, chief engineer, State Department of Public Health, Boston, Massachusetts, on "A Summary of the Sewage Experimental Work Done at the Lawrence Experiment Station During the Period from 1929–1938."

There was some general discussion from the floor on all of the above papers. The morning session adjourned at 12:45 P.M.

The members met for luncheon in the main dining room of the Toy Town Tavern at 1:00 P.M. The election of officers took place at 2:00 P.M. at the beginning of the afternoon technical session. The nominating committee submitted the following names:

For President—Mr. Arthur D. Weston of Boston, Mass.
For First Vice-President—Mr. W. P. Petrie of Norwalk, Conn.
For Second Vice-President—Mr. Walter J. Shea of Providence, R. I.
For Secretary-Treasurer—Mr. L. W. Van Kleeck of Hartford, Conn.
For Directors—Mr. J. A. Muldoon of Bridgeport, Conn.
Mr. Clarence F. Lamb of Providence, R. I.
Mr. Harold L. Brigham of Marlboro, Mass.

These officers were elected by the membership and the secretary was instructed to cast one ballot for the candidates. As usual, retiring President F. W. Gilcreas will serve as ex-officio member of the Executive Committee for the year 1940.

The technical session in the afternoon was opened by Mr. Joseph A. Tourigny, chief operator, Leominster sewage treatment plant, Leominster, Massachusetts, on "Operation of the Leominster Activated Sludge Plant."

Discussion on the Leominster plant was followed by a round table discussion on the "Uses of Lime in Sewage Treatment," opened by Mr. Charles G. Agar, sanitary engineer, New York State Department of Health and Mr. S. E. Coburn, sanitary chemist, Metcalf & Eddy, Boston, Massachusetts.

The last topic at the afternoon session was on "Experiences with Screenings Disintegrators." This was discussed by Mr. Guy E. Griffin of Greenwich, Connecticut, Mr. William J. Hanrath of Pittsfield, Massachusetts, and others.

The late afternoon was given over to enjoyment of the many attractions at Toy Town Tavern, following which the Association banquet was held at 7:00 P.M. After the evening banquet, Mr. Robert Spurr Weston, member of the Association, presented a traveling bag to retiring President F. W. Gilcreas in appreciation of his long and untiring service to the Association. The guest speaker was Mr. George O. Mansfield, chief fire inspector for the Massachusetts Department of Public Safety, who spoke on "How We Catch the Fire Bugs." This was an illustrated lecture for which the guest speaker was warmly

thanked by a well-entertained audience. The closing evening event was dancing.

While the men toy-led at Toy Town, the ladies were entertained under the direction of Mrs. E. Fred Cullen, Tavern Hostess. A putting contest, bridge and other games were enjoyed by the ladies. Prizes were awarded by the President following the evening banquet.

On Saturday, September 30, the Association breakfast was held at 8:15 A.M., following which Mr. Herbert B. Allen, supervising chemist of the Fitchburg sewage treatment plant, Fitchburg, Massachusetts, spoke on the recent operation of the Fitchburg sewage plant. An auto caravan left at 9:30 A.M. for an inspection trip of the Fitchburg sewage plant. This was followed by an inspection of the Leominster sewage treatment plant, which inspection completed the official program.

LeRoy W. Van Kleeck, *Secretary*

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Fall Meeting

Olean, N. Y., October 6–7, 1939

The Fall meeting of the New York State Sewage Works Association was held at Olean, N. Y., October 6 and 7, 1939, with headquarters at the Olean House, with N. L. Nussbaumer of Buffalo presiding. One hundred and twenty-five guests were registered.

On Friday morning, Nelson M. Fuller, Sanitary Engineer of the Cattaraugus County Department of Health, presented a very interesting paper on "Sewerage and Sewage Treatment in Cattaraugus County" with special emphasis on the geological formations and their effect on the special need for the protection of water supplies. Following this, William A. Ryan, Sanitary Chemist of Rochester, presented a paper on "Effect of Cannery Wastes on Operation of Sewage Treatment Works," the discussion of which was opened by Mr. Ralph D. Bates and Mr. C. J. Bernhardt, District Engineers of the State Department of Health at Buffalo and Jamestown respectively. There was also considerable discussion from the floor showing that this problem is quite widespread.

At the luncheon Dr. H. R. O'Brien, County Health Commissioner, welcomed the group and the Hon. John E. McAuliffe, Mayor of the City of Olean, and Hon. C. D. Constantine, Mayor of Franklinville, gave brief addresses.

At the afternoon session, a paper on "Study of the Development of Sewage Oxidation by a Trickling Filter," prepared jointly by F. W. Gilcreas, Associate Sanitary Chemist, and W. W. Sanderson, Senior Sanitary Chemist of the Division of Laboratories and Research of the State Department of Health, Albany, was presented by the latter and proved most interesting. One of the special features at the afternoon session was a symposium on "An Operator's Day at a Sewage Treat-

ment Plant," led by C. C. Agar of the New York State Department of Health, at which nine sewage plant operators gave the diary of their day's work.

Another feature of the meeting was the Gadget Competition, at which there were 15 entries of rather unusual merit. As a result of the ballots on these gadgets, the following awards were made:

First Award for "Chlorine Tank Alarm." Submitted by H. O. Johnson and Fred M. Jablon, Belgrave Sewer District, Great Neck, N. Y.

Second Award for "Artificial Light Cabinet for Color Determination." Submitted by Joseph E. Rehler, Olean, N. Y.

Third Award—For this there was a tie between the two following entries: (*A*) "Flag Pole and Weather Vane." Submitted by Ernest Larsen, Geneva, N. Y. (*B*) "Two Bottle Sampler." Submitted by George D. Carpenter, Ithaca, N. Y.

Following the dinner and usual entertainment, Friday night, Nelson M. Fuller showed two moving picture reels prepared by the Massachusetts Institute of Technology on high-speed photography, which greatly interested the group. On Saturday morning, as a part of the Sunrise Breakfast, a Question Box and a very able discussion of safety devices was presented by Mr. Nelson W. Hartz of the Mine Safety Appliance Corporation, during which he demonstrated several types of equipment. Following this, a description of the Olean sewage treatment works and a description of the Wellsville treatment works was given and the group proceeded to the Olean sewage treatment plant. In the afternoon, those present broke up into several groups for post convention trips to the Olean sewage treatment plant, the Franklinville sewage treatment plant, the Wellsville sewage treatment plant, and the oil fields in the general vicinity of Bolivar.

The next meeting of the Association will be the Twelfth Annual Meeting, which will be held in New York City, January 18, 19 and 20, 1940 at the Hotel McAlpin.

A. S. Bedell, *Secretary*

Reviews and Abstracts

H. W. Streeter

REPORT OF THE (BRITISH) WATER POLLUTION RESEARCH BOARD FOR THE YEAR ENDED 30th JUNE, 1938. (WITH REPORT OF THE DIRECTOR OF WATER POLLUTION RESEARCH)

This Eleventh Annual Report deals with various investigations conducted by the Board during the preceding year, including the exhaustive study of the effects of sewage and trades wastes on the character of mud in the River Mersey, the continued study of treatment of milk effluents and new investigations on the bacteriology of fresh water and the treatment of sewage by percolating filters. The report of the Director gives details of these investigations and also of studies concerned with water and its treatment, such as the base-exchange method of water softening, the removal of acids, bases and salts from water by synthetic resins, the contamination of water by lead and the sterilization of slow sand filters.

Milk Effluents. Experiments have been in progress since 1935 on the treatment of waste waters from milk collecting and distributing depots and from the manufacture of cheese, butter, condensed milk and other dairy products. At one large scale experimental plant milk washings have been treated by filtration through two percolating filters in series, with periodic change in the order of the filters. At another plant, treatment by the activated sludge method has been studied. During the past year whey washings and mixtures of whey and milk washings have been treated at the two plants.

It was found that milk washings, after sedimentation and dilution, if necessary, with purified effluent to give a mixture with a B.O.D. of 200–300 p.p.m. could be treated successfully by passage through the two percolating filters at a rate of 160 gal. per day per cu. yd. of filtering material. Under these conditions an effluent with a B.O.D. less than 10 p.p.m. was obtained. For short periods treatment was successful at a 240-gal. rate. In the activated sludge plant a well-purified effluent, with B.O.D. of 10 p.p.m. was obtained by aerating 24 hours settled and diluted milk washings with a B.O.D. of 500 p.p.m. The behavior of the plant when treating whey-milk washing mixtures was similar to its behavior when treating milk washings alone. No ponding of the filters occurred when their order was changed at two-week intervals. Detailed results of both series of experiments are given in tables.

Laboratory experiments have been continued on the effect of temperature on the purification of milk washings by the activated sludge process, the temperature range studied being 2°–45° C. The liquid was aerated by revolving brushes dipping below the surface of the liquid and revolving on a horizontal axis. The optimum temperature appears to be about 30° C. At 2° C. the sludge settled much less rapidly and the B.O.D. of the effluent was as high as 200 p.p.m. At 45° C., the B.O.D. of the effluent was high both after settlement and after filtration through paper, indicating that most of the oxygen-absorbing material was in solution.

Studies of the biological film on the filters and of the activated sludge in the aeration tanks have indicated that the most abundant form in the filter film was *Saprolegnia* sp. Protozoa were abundant during the treatment of whey mixtures, and also nematodes, *psychoda* larvae and other metazoa. In the activated sludge *sphaerotilus* was abundant when milk washings were treated, but diminished when whey washings were added. "Bulking" of the activated sludge occurred on several occasions when whey mixtures were being treated. Deterioration in the character of the sludge was not due to the presence of *sphaerotilus,* but probably to breaking up of flocs, facilitated by the

absence of *sphaerotilus,* and to a change in the character of bacteria, which did not form zoogleae as readily in the presence of whey washings as when milk washings were being treated.

Activated Sludge Process of Sewage Treatment. An investigation of changes in nitrogenous compounds when a mixture of settled sewage and activated sludge is aerated has been continued. The results, shown in a series of tables, have indicated in general a conversion of ammoniacal nitrogen to organic nitrogen, with little or no loss of nitrogen from the system. When potassium nitrite was added, a loss of nitrogen resulted from decomposition of the nitrite on aeration, with liberation of gaseous nitrogen. A similar result was noted when nitrate was added, owing to the formation of nitrite and its decomposition.

From laboratory experiments on the effect of temperature on the treatment of settled sewage with activated sludge, it was shown that at 30° C. a well nitrified effluent with low B.O.D. was obtained. A satisfactory effluent also resulted at 20° C., but was unsatisfactory at 5° C. and 10° C.

In the preceding report, results were given of experiments on passing air, oxygen, nitrogen and hydrogen through mixtures of sewage and activated sludge. The results of these experiments indicated that the main factor in the flocculation of sewage by gas bubbles is physical, though it is also influenced by biological action. It is possible that flocculation of organic matter might be caused by adsorption of such matter on the surface of the bubbles. If this were so, it would be expected that for a given volume of gas the quantity of organic matter flocculated would increase with diminished bubble sizes, as then the surface area for adsorption would be increased. Experiments on this point indicated, however, that change in the bubble surface area had no appreciable effect on the amount of organic matter flocculated.

Experiments were continued on the effect of adding synthetic resins to sewage, with treatment of the mixtures by air bubbles. Two resins were used: (1) M-phenylenediamine resin, which has acid-exchange properties; and (2) sulfited quebraco tannin resin, which has base-exchange properties. The experiments were carried out to test a previous suggestion that base-exchange is of importance in the treatment of sewage by the activated sludge process. The results indicated that preliminary treatment of the acid-exchange resin with sodium hydroxide and of the base-exchange resin with hydrochloric acid had little effect on the removal of organic carbon and total nitrogen from the sewage. Aeration with the acid-exchange resin caused a comparatively rapid removal of organic carbon, but had no effect on the removal of organic nitrogen. With the base-exchange resin, the amount of total nitrogen removed was increased and the rate of organic carbon removal was retarded.

River Mersey Investigation. As a special report of this investigation has been previously abstracted (THIS JOURNAL, **10**, 4, 802–3) it will suffice to note here that the investigation was undertaken to ascertain the effect of the discharge of sewage into the Mersey estuary on the amount and hardness of the deposit in the estuary. After reviewing the investigation, which was both comprehensive and thorough in its scope and method, the present Report restates the general conclusion that the mud found in the estuary is similar in composition and its resistance to erosion to mud deposited in substantially unpolluted localities; hence that the discharge of crude sewage into the estuary has no appreciable effect on the amount and hardness of these deposits.

Other topics discussed in the Report include the work of the Freshwater Biological Association and of the Liquor Effluents and Ammonia Committee of the Institution of Gas Engineers. In the former connection, reference is made to a bathginetric survey of Lake Windermere, using echo-sounding equipment for measuring the thickness of soft mud deposits.

H. W. STREETER

SOME CHEMICAL AND BACTERIOLOGICAL PROPERTIES OF TRADE WASTES CONTAINING CHROMATES

By H. E. Monk, *County Analyst, Worcestershire County Council*
Surveyor, **96**, 69–71 (July 21, 1939)

The only trades known to be responsible for waste containing chromates are the leather industry, where it uses chrome tanning, chromium plating, and the oxide coating of metals by the anodizing process. As the latter process is the only one recently developed and as difficulties with chromate wastes have only recently been experienced, it is suggested that the wastes from the anodizing process may be more troublesome than the wastes from the older trades.

The chromium plating and anodizing processes are compared. The principal differences are:

	Chromium Plating	Anodizing Process
Work being plated is the	Cathode	Anode
Strength of chromic acid plating bath	30%	3%
Frequency of discharge of plating bath	rarely or never	Replaced after strength has been made up three times
Previous coatings applied to work	Usually nickel Sometimes copper	None
Relative current density	High	Low

From chromium plating the principal waste is rinse water consisting mainly of dilute chromic acid or chromates. During a month of observation in one factory, chromate (as CrO_3) averaged 100 p.p.m. in the waste and varied from 0 to 173 p.p.m. Strong acids, alkali, etc., are also used for cleaning and preparing the work for plating.

Chromate wastes may have an influence upon sewers, sewage purification processes, and streams receiving effluents carrying the wastes. In this paper the effects are discussed under two headings: chemical and bacteriological.

Chemical effects due to chromates may be due to acidity, oxidation, action on proteins, precipitation of colloids.

Acidity: High acidity would only occur with rapid discharge of anodizing vat liquor into a quiescent sewer of low gradient. The most important effect would probably be the decomposition of soaps with the formation of a sticky mass of free fatty acids. This would be a contributory factor to blocking of sewers.

Oxidation: In experiments with 100 p.p.m. CrO_3 added to a mixture of sludge and distilled water, H_2S did not develop and the sludge remained light gray in color. This effect occurred even with 50 p.p.m. CrO_3, after some days. The light gray sludge appears to be typical of chromate conditions.

Action on Proteins: In a sewer carrying wastes averaging 100 p.p.m. of CrO_3 and probably never exceeding 173 p.p.m. (for a two month period), sludge was found to contain 2780 p.p.m. CrO_3, in the wet sludge. These observations suggest some kind of combination between the chromate and protein. As an explanation of absence of such observations from chrome tanning plants, it is mentioned that possibly the adsorption here had occurred before the wastes entered the sewer and often prior to settling of the leathery compounds at the tannery settling basins.

Precipitation of Colloids: Experiments made by adding anodizing wastes to well-mixed domestic sewage indicated that with increasing addition of chromate, a marked increase in quantity of precipitated matter occurred. From analyses of sludge and liquid it is concluded that this effect was a colloid precipitation rather than an adsorption process as discussed under action on proteins.

Bacteriological Effects: As an approach to a forecast of what strength of chromates might be allowable in sewage without harm to the purification process, it was decided to test the effect of varying concentrations of CrO_3 upon suspensions of *B. Aerogenes*. The procedure followed and experimental results are reported in some detail.

It was considered that conditions which did not kill more than 50 per cent of the *B. Aerogenes* in two hours contact time might be allowable. The experimental work indicated further that this would occur if the CrO_3 content of the sewage did not exceed 50 p.p.m.

A full scale trial was then carried out. Two experimental discharges of anodizing swill liquor were arranged from a large factory to a small sewage works. Examinations of the plant influent and effluent were made on the day of the discharge and on the days before and after, with the following results:

First Trial	Percentage Purification			
	Day Before	Day of Discharge (two tests)		Day After
Purification as indicated by:				
1. Albuminoid Ammonia	77	76	72	66
2. Oxygen Absorbed	67	76	70	70
3. Average	72	76	71	68
Second Trial	**Day Before**	**Day of Discharge (two tests)**		**Day After**
Purification as indicated by:				
1. Albuminoid Ammonia	39	74	62	72
2. Oxygen Absorbed	56	77	59	83
3. Average	48	75	60	77

F. E. DeMartini

CHELTENHAM'S REMODELLED SEWAGE DISPOSAL WORKS

By G. Gould Marsland, *Borough Surveyor and Water Engineer*
Surveyor, **96**, 71–72 (July 21, 1939)

A number of interesting and useful points are mentioned in this paper. The original Hayden Works, receiving most of Cheltenham's sewage, were built piecemeal starting in 1907. Previously, land disposal only was followed but the plan drawn up in 1905 was based on use of tanks and percolating filters. The units were installed as follows: Detritus tanks 1907, three settling tanks, 1910, nine settling tanks and eight filters, 1914–15, four humus tanks, 1922, completing the original plan. In 1926 five additional filters were built due to increased sewage flow.

In 1927 experiments were carried out to study the effect on the treatment plant of spent gas house liquor. These experiments indicated that spent gas liquor to the extent of 0.5 of 1 per cent of the dry weather flow discharging continuously throughout the 24 hours could be handled. After 5 years the experiments were repeated with the substitution of ammoniacal gas liquor for the spent gas liquor. Again it was found that 0.5 of 1 per cent of the dry weather flow could be dealt with. Plant results with ammoniacal gas waste in the sewage were as follows:

SUMMARY OF RESULTS

0.5 of one per cent. Ammoniacal Gas Liquor
(Results in parts per 100,000)

Description	Suspended Solids	Free and Saline Ammonia	Albuminoid Ammonia	Chlorine as Chlorides	Oxidized Nitrogen	Oxygen Absorbed in 4 hrs. 80° F.
Crude sewage.....	19.00	5.85	1.33	10.80	Nil	10.90
Settling tank effluent.....	3.50	6.33	0.72	9.60	Nil	7.70
Final effluent.....	1.50	1.55	0.21	9.60	4.00	1.00

These results indicate the heavy loading on the percolating filters. Early in 1934 pooling of the filters occurred. Investigation showed that both the strength and quantity of sewage had increased considerably. An accompanying increase in solids resulted in accumulation of undigested sludge that could not be disposed of. The outcome was development of a new scheme for partial sludge digestion by addition of four open, unheated tanks, having a capacity of 1 cu. ft. per capita of contributing population. Other improvements were as follows: Installation of two Lea Flume recorders on outfalls leading to the plant, reconstruction of the storm overflow structure, installation of an electric driven grit elevator to replace a hand operated unit, construction of six new percolating filters (5 are 101 ft. in diameter and one 40 ft. in diameter). These filters are 4 ft. 9 in. deep and filter material is granite graded in three layers as follows: Bottom layer, 6 in. thick, of 3 in. to 4 in. gauge granite; middle layer, 3 ft. 7 in. thick, of 1½ gauge material; and top layer 8 in. thick, of ¾ in. gauge material. The distributors are of the two arm type.

It was found that clay underlying the site was heavily charged with sulphates. Acting on advice from the Building Research Association, Ciment Fondu was used in those structures likely to be affected so as to avoid deleterious action on the cement concrete.

Since completion of the changes all units have operated satisfactorily. The added filter capacity allows for resting of filters. Sludge digestion has solved the sludge disposal problem as farmers now take all the sludge. The author concludes that settling tanks and percolating filters have a definite place in sewage treatment and that the golden rule to follow is to adopt the simplest type of treatment which it is known will give the required results.

F. E. DEMARTINI

THE APPLICATION OF FLUORESCENT INDICATORS TO THE ACIDIMETRY OF TRADE EFFLUENTS

BY DENIS DICKINSON

The Surveyor, 93, 86b (1938). Discussion, *The Surveyor*, 93, 240–41

In the use of fluorescent indicators since the change of the indicator with pH is a change in fluorescence and not of color these indicators may be used in all solutions except those possessing an intense color. The fluorescence of fluorescein, visible in alkaline solution only, disappears quite sharply at pH 7.0. Umbelliferone also recommended for use has a sky-blue fluorescence in alkaline solution which fades when a pH of 7.0 is reached. Its fluorescence is easily detectable in highly colored solutions. A large majority of the fluorescent indicators fluoresce in alkaline solution and are therefore best employed in the titration of acids with alkalies. It is possible, however, to titrate an alkaline solution by adding an excess of acid and back titrating. Acridine may be used as a fluorescent base, possessing a faint sky-blue fluorescence in alkaline and a

brilliant yellow-green fluorescence in acid solution. Its pH range is approximately 5.3–7.0. The green fluorescence first appears at pH 7.0 but fades on shaking, becoming permanent at pH 5.3. Most of the fluorescent indicators are best used when the titrations are carried out in ultra-violet light. However, fluorescein, acridine and umbelliferone may be used in ordinary daylight, provided the solution is viewed by reflected light. A table in the original paper gives some results obtained with various indicators.

The presence of certain substances such as toluene, phenol, dyes of the diphenyl type, etc., interfere with the use of fluorescent indicators. However, since the action appears to be selective a suitable indicator can usually be found. As a general rule such compounds are not present in sufficient quantities to effect the use of the indicator.

W. Allan Moore

THE SYSTEM ACTIVATED SLUDGE/OXYGENATED WATER

By Denis Dickinson

The Surveyor, 93, 86a–86b (1938), Discussion, *The Surveyor*, 93, 240–41 (1938)

When samples of activated sludge, unit liquor, and mixtures of activated sludge and effluent were aerated mechanically and by air bubbles in the presence of methylene blue in no case was the purification superior to that of the blanks. During the aeration period it was found that the color of the dye was not discharged. However, activated sludge will reduce the dye to the leuco base if allowed to stand in contact with it without aeration. These facts are explained by the oxidation/reduction balance. The reduction of dyes such as methylene blue may be expressed by the equation

$$E_h = E_0' + K \log \frac{\text{reduced form}}{\text{oxidized form}}$$

in which E_h is the electrical potential of the solution on the hydrogen scale and E_0' and K are constants. If the system activated sludge/oxygenated water be expressed as,

oxygen/reduced form

then on adding methylene blue to the solution the extent to which the dye is reduced depends upon the relative cencentrations of dissolved oxygen and the reduced form. Since, during aeration the concentration of dissolved oxygen should be fairly constant then the above ratio should be constant. Therefore, the dye is only partly reduced. It is doubted that methylene blue acts as a catalyst in sewage purification since the equilibrum potential of the process E_0', corresponds closely to that of methylene blue itself. An attempt was made to determine the percentage decolorization effected by a sample of activated sludge by the following method: 0.1 ml. of a 0.5 N methylene blue solution was diluted to 50 ml. with boiled distilled water and a portion of the solution sealed in a thin walled tube. 25 ml. of the remainder was also diluted to 50 ml. In this way standards corresponding to 0, 25, 50, 62.5, 75, 87.5 and 95 per cent were obtained. In order to determine the percentage reduction of a sludge, 5 ml. was added to 45 ml. of B.O.D. water contained in a 50 ml. graduate, followed by 0.1 ml. of the methylene blue solution. The surface of the solution was protected by a layer of paraffin oil. The mixture was gently stirred then allowed to stand for 0.5 hour after which the color was compared with the standards. It was found by percentage decolorization/time curves that the initial rate of decolorization was quite rapid but remained constant after 0.5 hour. In a long series of experiments carried out no relation could be found between the percentage decolorization and total solids, ash, volatile solids, oxygen consumed after 4 hours, or the B.O.D. It was found that if the sludge was kept stirred while in contact with the dye the percentage decolorization was less than if the sludge was allowed to settle. It was also noticed that the settled sludge was dyed blue. Sometimes in settling the color was discharged from the body of the sludge but persisted at the solid/liquid interface. Apparently the absorption of the dye precedes its decolorization. The sludge

also absorbs oxygen from the solution thereby reducing the potential of the solution which also causes reduction of the indicator. If to a "good" sludge is added methylene blue it is found that absorption only takes place, there being no reduction of the indicator. However, if a "poor" sludge is treated with methylene blue there is both reduction and absorption. The results obtained according to the author seem to indicate that the decolorization of methylene blue is a fair indication of the degree of activation of a sludge.

Discussion

F. W. Allen (Bolton) raised the objection to the author's work that he had not standardized his sludges in regards to total solids which might cause a difference in results obtained. The results obtained when activated sludge was stirred and simply allowed to settle when in contact with methylene blue were also criticized by Mr. Allen. He expressed the opinion that the reason the percentage decolorization in the former case was lower was simply due to oxygen being absorbed during the stirring and therefore less of the dye was apparently reduced.

Dr. W. Watson (Burnley) stated that experiments carried out by himself indicated that stirring of the sample increased the adsorption of methylene blue which was contrary to Mr. Dickinson's findings. He agreed with Mr. Allen that adsorption of atmospheric oxygen was the answer to the question for he had found previously that a layer of paraffin oil on the top of the liquid did not prevent atmospheric oxygen from entering the liquid. He suggested that if Mr. Dickinson had carried out his experiments in well-stoppered bottles he would have found that shaking increased the adsorption of methylene blue. Dr. Watson said that he had carried out an experiment since Mr. Dickinson's paper had been presented. He had added methylene blue to both a "good" and a "bad" activated sludge in well stoppered bottles and could see no difference in the degree of adsorption.

Mr. J. P. Todd (Ashton-under-Lyne) suggested that the determination of the partition coefficient of methylene blue between activated sludge and liquor would have been a better way to approach the problem.

In reply to Mr. Allen concerning the standardization of the solids content of the various sludges Mr. Dickinson said that he had taken that into consideration when he stated there was no correlation between the percentage decolorization and any of the constituents determined.

In answer to Mr. Allen's (also Dr. Watson's) question as to why the percentage decolorization of the stirred sludge was less than that of the settled sludge Mr. Dickinson said that he had not allowed the stirred sludge to settle while making the comparison and one was therefore not only looking at the methylene blue in solution but also observing that adsorbed. He did not think that atmospheric oxygen was adsorbed fast enough to effect the comparisons as shown in the table.

W. Allan Moore